INFLUENCE OF DYNAMIC AND PLYOMETRIC EXERCISES ON KNEE JOINT MOTION FOR COUNTERMOVEMENT JUMP PERFORMANCE

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This study aimed to analyze the effects of dynamic and plyometric exercises on knee joint motion for countermovement jump (CMJ) performance. The CMJ test was performed in 45 male college non-athletes who were categorized into three groups: a dynamic exercise group performing dynamic exercises, a plyometric exercise group performing jumping exercises, and a control group performing traditional exercises for physical education. Motion analysis data from the knee joint angles were obtained during countermovements in the sagittal plane using video recording. The results showed that plyometric and dynamic exercises could improve jumping performance in college non-athletes and enhance the strength, force, and power of the lower limb muscles and joints. Furthermore, the motion analysis helped identify a range of motion of the knee joints during dynamic and plyometric exercises that contributes to jumping performance.

KEYWORDS: countermovement, plyometric, jumping kinetics

INTRODUCTION: The countermovement jump (CMJ) test is widely used in monitoring athletic performance. Differences in CMJ performance are related to the effective use of the stretch-shortening cycle, wherein the muscle function starts with an eccentric action, followed by a concentric action (Nicol, Avela, & Komi, 2006).

Recent literature in the field has reported contributions of the knee and hip joints with a large or small range of motion and effects of lower limb muscle strength on vertical jump performance. Gheller et al. (2015) and Pérez-Castilla, Rojas, Gómez-Martínez, and García-Ramos (2019) report evidence that jumping with the knees more bent improves the knee starting angle, velocity, and countermovement depth, inducing better CMJ performance. Plyometric jumping protocols are characterized by a transition of rapid eccentric muscle contraction to rapid concentric contraction, producing specific neural adaptations, increasing the activation of motor units, and producing maximum muscle force in a short period, thus improving power and speed (Slimani et al., 2016). Similarly, dynamic exercises involve a full range of motion and high neuromuscular activation, thus enhancing power and agility. Researchers have found that dynamic and plyometric exercises can effectively improve jumping performance (Stojanović, Ristić, McMaster, & Milanović, 2017).

The purpose of this study was to analyze the effects of dynamic and plyometric exercises and to compare their efficacy in improving jumping kinetics among college physical education (PE) students. During countermovement moment, the knee joint angle (KA) was obtained to determine possible changes in CMJ kinematics. We hypothesized that the KAs would negatively affect CMJ performance in college non-athletes.

METHODS: This study included 45 male college non-athletes with a mean age of 19.04±0.88 years, height of 168.51±5.62 cm, and weight of 58.94±9.45 kg. Our Institutional Review Board approved the study, and the subjects were informed in writing in relation to the study.

Procedures: The subjects were divided in three groups for data collection: a control group (CG), a dynamic exercise group (DG), and a plyometric exercise group (PG). The groups performed a 10-to-15-min warm-up protocol. Thereafter, each subject performed one CMJ. Motion analysis and CMJ data were collected using the GoPro HERO5 Black version 2.70 recording at 240 Hz, the myDartfish Express application, an iPad Pro (10.5 in; iOS 11.3), and two 0.75-m aluminium tripods calibrated at 90°. The angle of the GoPro and iPad cameras was adjusted to a horizontal and vertical position, respectively, at 90° in front of the subjects. The GoPro camera was located 2 m facing the subjects in the saggital plane. Conversely, the iPad camera was located 3.70 m facing the subjects in the frontal plane and zooming in on their feet (Gallardo-Fuentes et al., 2016). This location allowed the teachers to record the complete movement of the CMJ. The subjects were asked to jump at maximum effort from the initial position.

Protocols: The PG was instructed to perform a 15-min warm-up, consisting of dynamic activity for 5 min and plyometric jumps for 10 min in the following order: squat jump, CMJ with and without the arms, and jumping lunges. The PG completed three sets of 10 repetitions each, with 15-sec rest after a set and 45-sec rest after a new exercise. The DG was instructed to warm up for 10 min using dynamic exercises in the following order: jogging with the arms oscillating forward and backward, lateral shuffle, carioca back and forth, high knee pulls, high knees, butt kicks, lunges with trunk torsion, and two sprints. The DG completed two sets of each exercise over a distance of 20 m. The CG was instructed to perform a 10-min warm-up, which included traditional exercises used in college PE class, such as 400-m track jogging, static and dynamic stretching (upper and lower limb flexes, extensions, and rotations for eight repetitions; triceps, shoulder, quadriceps, hamstring, and groin stretch for 8 sec). The PG, DG, and CG had one class per week. The subjects were assessed at three different periods in the CMJ test performed with maximum effort.

Kinematic Analysis: KA data were obtained using the myDartfish Express application. The videos were analyzed using still shots at 8 Hz. Data were obtained from the three tests in all subjects. The convention for measuring the KAs was to measure using the knee joint as a reference point in the direction of the lateral condyle along the fibula, finishing at the ankle joint, and from the lateral condyle to the greater trochanter, finishing at the hip joint. The KA was measured during the countermovement moment of the CMJ in the sagittal plane; that in one complete phase of a CMJ was included for data analysis. The KA and CMJ performance were compared among the groups.

Statistical Analysis: CMJ performance was measured in the frontal plane using the My Jump 2 application (Stanton, Kean, Scanlan, 2015). This application calculated the time (in milliseconds) between the take-off and landing frames, which were selected by the teachers, and then the CMJ height, push-off, power, force, velocity, and flight time (Gallardo-Fuentes et al., 2016). The KA was measured in the sagittal plane via two-dimensional video recording of the participants using the myDartfish Express camera. The following variables were analyzed: KA and CMJ height, push-off, flight time, velocity, force, and power. Age, sex, height, and weight were also included in the data analysis. Effect-size statistics were assessed using Cohen's d as small (<0.2), medium (<0.5), or large (<0.8). The obtained data were analyzed using descriptive statistics (mean ± standard deviation) and multi-factor ANOVA SPSS Statistics® software version 26, with the significance level set at $p \leq 0.05$.

RESULTS: Forty-five healthy male college non-athletes were included in this study. Subjects with injuries or who did not complete the protocols during the evaluation were excluded. Multiple comparisons among the DG, PG, and CG were performed. The push-off, force, and power (main effects) among the groups showed significant differences ($p=0.000$); conversely, the flight time ($p=0.685$) and velocity ($p=0.679$) did not.

Table 1: Knee joint angle (°), jump length (cm), push-off (Hp0 in m), force (N), power (W) and groups' mean and SD values

	Group	Mean	SD	N
Jump height (cm)	CG	42.97	5.67	14
	PG	43.59	7.21	17
	DG	45.12	6.80	14
	Total	43.87	6.55	45

Knee joint angle (°)	CG	70.75	12.42	14
	PG	71.04	9.36	17
	DG	70.49	11.46	14
	Total	70.78	10.78	45
Push-off (Hp0 in m)	CG	0.37	0.09	14
	PG	0.29	0.04	17
	DG	0.21	0.03	14
	Total	0.29	0.09	45
Force (N)	CG	1354.73	404.44	14
	PG	1405.97	218.41	17
	DG	1819.15	311.29	14
	Total	1518.57	369.45	45
Power (W)	CG	1947.72	528.03	14
	PG	2051.44	382.91	17
	DG	2714.30	606.49	14
	Total	2225.40	597.20	45

SD, standard deviation; CG, control group; PG, plyometric exercise group; DG, dynamic exercise group

Among the CG, DG, and PG, the jump height (p=0.680) and KA (p=0.990) did not show any significant difference. Cohen's effect size was small for the KA and jump height, flight time, velocity, force, power, and push-off.

DISCUSSION: Recent literature showed that a countermovement phase smaller than 90° or jumping with a squat depth position yielded the best jump performance and that CMJ performance would be affected by different KAs (Gheller et al., 2015). To assess these, this study measured the KA of the PG, DG, and CG during the countermovement phase of the CMJ. The analysis showed that the KA did not significantly differ among the groups. However, the differences in the KA kinetics may be associated with the improvement of jump performance (Kariyama, 2019). Plyometric jumping exercises utilize the stretch-shortening cycle, yielding a different range of knee joint motion. This type of exercise can enhance the mechanical output of the lower limbs, improving muscle and tendon function. A higher muscle stretch tolerance can be interpreted as an increase in the range of joint motion.

Plyometric and dynamic exercises induce explosive force and power by increasing the neuromuscular function. A significance has been recorded for push-off, force, and power among the groups. The countermovement allowed the subjects to attain greater knee joint moments at the start of push-off. The KA during push-off had to reach 90° or lower before starting the jump, and the descending movement of the push-off had to be performed with a rapid descend (Bobbert, Gerritsen, Litjens, & Van Soest, 1996). Our study showed that the mean KA of the PG, DG, and CG was 70.78° during countermovement, which agrees with the suggested adequate range of knee motion in CMJs. The countermovement allows the muscle to rise to a level of high activity and force before starting to compress itself. This active muscle state at the beginning of the jump affects the force capabilities of the neuromuscular system. The greater force of the lower limb extensor muscles would contribute to a higher CMJ height. Plyometric and dynamic exercises are used to improve this muscle force and power production, and plyometric jumps are used to attain maximum isometric force. Therefore, plyometric and dynamic exercises should not be difficult to perform by college students and to put into practice during PE classes.

Jumping drills for plyometric exercises and low-to-moderate-intensity dynamic exercises could enhance power output capabilities. The analysis revealed that the jump height did not significantly differ among the PG, DG, and CG. However, potentiation of subsequent performance can be observed with low- and moderate-intensity dynamic exercises. Although plyometric exercises are considered highly effective for enhancing strength and power, the PG showed a lower height than did the DG preceding the CMJ test, conceivably owing to plyometric-induced fatigue. Plyometric jumping exercises and dynamic exercises were found to improve CMJ performance and enhance strength, force, and power among the college male non-athletes. A limitation of our study is that we did not control the fatigue effects from the warm-up protocols. Future studies should extend into different age groups, other sports-related PE classes, and more frequent weekly training sessions.

CONCLUSION: In this study, college PE teachers and coaches analyzed CMJ performance and distinguished jumping kinetics using mobile applications. This method of analysis can be used in sports-related PE classes or training sessions and can enhance the understanding of the range of knee motion and the influence of strength, force, and power on jumping performance. The range of motion of the knee joint can influence the countermovement phase in CMJ performance. For this reason, observing and evaluating the KAs during the countermovement phase and implementing plyometric and dynamic exercises can help improve the range of knee joint motion, jumping kinetics, and CMJ performance.

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