RESEARCH ARTICLE

Analysis and optimization of basketball player's motion state based on sports biomechanics

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To stand out in the competitive basketball games, players require not only exceptional skills and tactical knowledge but also scientific and efficient training methods and optimal athletic state. The primary objective of this study was to evaluate the impact of rapid expansion and contraction compound training on lower limb performance. This research involved a case study with 30 male players (20 ± 1.1 years) from the basketball team at the Hebei Institute of International Business and Economics (Qinhuangdao, Hebei, China). The participants engaged in rapid expansion and contraction compound training. Biomechanical assessments were conducted before and after the training to measure the height of the stop jump, ground reaction force, the range of angle variation in the hip, knee, and ankle joints, and the peak torque during the takeoff stage. The results showed that the height of the stop jump shot and the reaction force from the ground were significantly improved following rapid expansion and contraction compound training compared to that in pre-training measurements. The range of the flexion and extension angle in the hip and knee joints as well as the range of the dorsiflexion and plantarflexion angle in the ankle joint showed significant enhancement. The peak hip joint extension torque, knee joint flexion torque, and ankle joint plantarflexion torque all showed significant increases. The results suggested that rapid expansion and contraction compound training could effectively improve the lower limb motor abilities of players, providing an effective reference for enhancing the competitive performance of basketball players.

Keywords: basketball; sports biomechanics; lower limb joint; rapid extension; contraction; training.

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Introduction

The strength and flexibility of the lower limbs directly affect the performance of basketball players [1]. Lower limb strength provides support and explosive power during critical actions such as offensive and defensive transitions, jumping, and shooting. Additionally, flexibility in lower limbs improves players' movement speed and stability [2]. Therefore, basketball players need to pay attention to the daily training of their lower limbs. One effective method for developing lower limb strength is rapid extension and contraction compound training, which uses the rapid conversion between centrifugal and centripetal muscle contractions to improve muscle strength [3]. Although there are methods for exercising lower limb strength, players usually cannot recognize training effects and identify errors independently. Therefore, it is crucial for coaches to provide guidance, ensuring players achieve optimal training outcomes while minimizing the risk of sports injuries [4]. However, it is difficult for coaches to consider the needs of all players on the one hand, and it is also difficult for coaches to understand the sports status of different players more deeply based on personal experience on the other hand.

Sports biomechanics is a discipline that applies mechanical principles to examine the external mechanical motion of organisms [5], which can be applied to players' training. By employing measurement tools, it is possible to quantitatively analyze the motion state of players' lower limbs before and after training to test the optimization effect of rapid extension and contraction compound training on lower limb strength and help coaches adjust the training content and intensity based on the results of the quantitative analysis [6]. Liu investigated 20 college varsity basketball players and confirmed that core strength training could improve muscle strength, coordination, and balance [7]. Williams *et al*. explored the influence of ankle taping on the biomechanics of the ankle and knee joints in women during cutting and rebounding activities and found that ankle taping only limited the range of motion in the ankle joints during rebounding and had an upstream effect on the knee joint [8]. Struzik *et al*. explored whether physical activities such as running and jumping would affect the variables in maintaining body balance while standing in basketball players. The results showed that sports activities significantly impacted balance ability [9]. Playing basketball can exercise people's physical fitness and enrich their cultural life. However, in formal basketball games, the confrontation between players is intense. To gain an advantage in the game, not only a sufficient technical level is needed, but also corresponding requirements are placed on the players' physical fitness. Conventional training methods can improve the physical fitness of players to a certain extent, but they are difficult to target. Sports biomechanics integrates theories of biology, kinematics, and mechanics. Studying the mechanism of human movement helps coaches and players better understand the essential laws of basketball, thereby formulating more targeted training. This study applied sports biomechanics to investigate the improvement effect of rapid expansion and contraction compound training on the physical fitness of 30 college basketball players. The results of this study would provide an effective reference for the scientific and rational training of athletes.

Materials and methods

Research subject

The subjects of this study included 30 male basketball players from the Hebei Institute of International Business and Economics, Qinhuangdao, Hebei, China with the average age of 20 ± 1.1 years, a mean height of 179.3 ± 1.1 cm, a mean weight of 64.1 ± 1.1 kg, and no injury within three months. The procedures of this study were approved by the IRB Committee of Hebei Institute of International Business and Economics. All participants received and signed informed consent forms before being involved in the study.

Training methods

The rapid expansion and contraction compound training was adopted in this research [10]. The participants received the training 3 times a week on Monday, Wednesday, and Friday for eight weeks. The detailed training items and procedures were listed in Table 1.

Test methods

The basic structure of the test field layout for the biomechanics test included five high-speed Arqus A5 cameras (Qualisys, Göteborg, Sweden) that were evenly arranged in a 180-degree range around the force testing platform at the end of a one-meter-long run-up track to capture the takeoff stage of the subjects [14]. The camera's motion image capture frequency was set at 250 Hz. The collected image data were processed

Table 1. Schedule of training programs.

Training phase	Training program	Amount of training (times × sets)	Training point
Weeks 1 - 4	Ski steps	20 × 4	Maintain coordination between hands and feet, ensuring smooth and continuous movements. Strengthen the intensity and range of the pushing off from the ground as much as possible to ensure the movement standard [11].
	Lunge exchange jump	20 × 4	Ensure that the lunge was the appropriate size for the player and that they possessed sufficient push-off power and stability [12]
	Jump up and down quickly	10 × 4	Keep the body stable and the movement consistent during jumping to reduce the landing buffer time.
	Barbell neck squat	8 × 4	The weight of the barbell should be 30% of the maximum squat weight that the athlete could bear, and the thighs should be parallel to the ground when squatting. The whole process should be down slowly and up quickly [13].
Weeks 5 - 8	Jump small hurdle	10 × 4	Maintain balance in the body while jumping to minimize the duration of both feet touching the ground
	Drop jump	8 × 4	Keep the body balanced
	Jump large hurdle	8 × 4	Warm up properly before jumping to minimize the duration of both feet touching the ground after landing
	Barbell neck squat	8 × 4	

using Qualisys Track Manager (QTM) (Qualisys, Göteborg, Sweden). To make the camera more clearly capture the changes in lower limb joints during the takeoff stage, markers were applied to key joints, primarily including the hip, knee, and ankle joints. After the start of the test, the player dashed from the track's starting point, stopped abruptly when reached the takeoff point marked on the force testing platform, took off, and landed with the front foot [15]. The player kept the upper body perpendicular to the ground as much as possible during the whole takeoff process. The stop jump shot was taken as the test movement. The takeoff stage of this movement, which was from the sudden stop to the moment when the foot just left the ground after takeoff, was selected for the sports biomechanics test. Each participant repeated the stop jump three times. There was a break of one minute between each stop jump. In the measurement of the ground reaction force, to avoid the interference caused by the difference in the body weight, the ground reaction force was standardized by the body weight with the unit of BW.

Statistical analysis

SPSS (IBM, Armonk, NY, USA) was employed for statistical analysis. The data were presented as mean ± SD. Student t-test was used to check the difference before and after training. The *P* values less than 0.05 and 0.01 were defined as significant difference and very significant difference between the groups, respectively.

Results

The takeoff height and ground reaction force during the takeoff stage before and after training

The takeoff height and the maximum ground reaction force of the participants before and after the fast extension and contraction compound training showed that the takeoff

Table 2. The takeoff height before and after training and the maximum ground reaction force during the takeoff phase.

Indicator	Before training	After training	*P* value
Takeoff height (m)	0.32 ± 0.09	0.41 ± 0.11	0.031
Vertical ground reaction force (BW)	3.12 ± 0.67	3.60 ± 0.72	0.032
Forward ground reaction force (BW)	1.36 ± 0.03	1.37 ± 0.05	0.635
Backward ground reaction force (BW)	-1.32 ± 0.04	-1.34 ± 0.03	0.798
Inward ground reaction force (BW)	0.96 ± 0.02	1.11 ± 0.03	0.039
Outward ground reaction force (BW)	-0.12 ± 0.06	-0.11 ± 0.04	0.845

Table 3. The range of motion of the joint angles of the players before and after training in the takeoff phase.

Indicator		Before training	After training	*P* value
Hip joint	Flexion and extension (°)	44.11 ± 9.42	49.57 ± 6.35	0.011
	Adduction and abduction (°)	12.56 ± 3.52	15.05 ± 4.36	0.635
	Internal and external rotation (°)	11.58 ± 4.08	12.05 ± 3.77	0.847
Knee joint	Flexion and extension (°)	67.98 ± 7.45	74.64 ± 8.57	0.005
	Inversion and eversion (°)	9.15 ± 3.25	8.97 ± 1.42	0.936
	Internal and external rotation (°)	11.25 ± 3.62	10.65 ± 2.31	0.741
Ankle joint	Dorsiflexion and plantar flexion (°)	37.58 ± 5.87	43.68 ± 5.36	0.008
	Inversion and eversion (°)	24.57 ± 3.69	19.98 ± 4.58	0.006
	Internal and external rotation (°)	14.25 ± 3.21	16.93 ± 6.74	0.869

height of the players improved significantly from 0.32 ± 0.09 m to 0.41 ± 0.11 m after training (P < 0.05). The average vertical ground reaction force was 3.12 ± 0.67 BW before training and 3.60 ± 0.72 BW after training (P < 0.05), while the average inward ground reaction force was 0.96 ± 0.02 BW before training and 1.11 ± 0.03 BW after training (P < 0.05) (Table 2).

Changes in the joint angles of players during the takeoff stage before and after training

The range of motion of lower limb joint angles during the takeoff stage after the players perform the stop jump movement before and after training demonstrated that the flexion and extension angles of the hip joint were significantly improved from 44.11 ± 9.42° before training to 49.57 ± 6.35° after training (P < 0.05). However, the adduction, abduction, and internal and external rotation angles had no significant changes. The flexion and extension angles of the knee joint was 67.98 ± 7.45° before training and 74.64 ± 8.57° after training, which showed very significant difference before and after training (P < 0.01). The dorsiflexion and plantar flexion angle was 37.58 ± 5.87° before training and 43.68 ± 5.36° after training (P < 0.01), while the inversion and eversion angle was 24.57 ± 3.69° before training and 19.98 ± 4.58° after training (P < 0.01). The internal and external rotation angle did not change significantly (Table 3). The results indicated that the range of the dorsiflexion and plantar flexion angle was significantly increased after training, while the range of the inversion and eversion angle was significantly decreased.

The peak joint torque in the takeoff stage before and after training

The peak joint torques of the lower limbs in the takeoff stage before and after training showed that, in the hip joint, only the peak torque of extension increased significantly after training compared to that before training from -4.38 ± 1.63 Nm/kg to -3.58 ± 1.12 Nm/kg (P < 0.05), while the rest of the peak torque did not change significantly. In the knee joint, only the peak flexion torque and the peak extension torque were significantly changed after training from

Table 4. Peak joint torques of athletes before and after training in the jump phase.

Indicator		Before training	After training	*P* value
Hip joint	Peak flexion torque (Nm/kg)	2.06 ± 0.57	2.19 ± 0.69	0.978
	Peak extension torque (Nm/kg)	-3.58 ± 1.12	-4.38 ± 1.63	0.034
	Peak adduction torque (Nm/kg)	0.72 ± 0.36	0.85 ± 0.57	0.735
	Peak abduction torque (Nm/kg)	-1.98 ± 0.54	-2.15 ± 0.88	0.725
	Peak torque of internal rotation (Nm/kg)	0.57 ± 0.16	0.64 ± 0.23	0.907
	Peak torque of external rotation (Nm/kg)	-1.57 ± 0.39	-1.66 ± 0.32	0.982
Knee joint	Peak flexion moment (Nm/kg)	-1.48 ± 0.45	-2.65 ± 0.38	0.007
	Peak extension torque (Nm/kg)	3.51 ± 0.66	2.92 ± 0.57	0.042
	Peak inversion torque (Nm/kg)	0.52 ± 0.07	0.52 ± 0.21	0.806
	Peak eversion torque (Nm/kg)	-0.85 ± 0.33	-0.92 ± 0.23	0.302
	Peak torque of internal rotation (Nm/kg)	0.75 ± 0.16	0.67 ± 0.15	0.511
	External torque of external rotation (Nm/kg)	-0.31 ± 0.12	-0.34 ± 0.06	0.917
Ankle joint	Peak dorsiflexion torque (Nm/kg)	0.93 ± 0.67	0.68 ± 0.54	0.004
	Peak plantar flexion torque (Nm/kg)	-2.47 ± 0.45	-3.15 ± 0.32	0.013
	Peak inversion torque (Nm/kg)	0.42 ± 0.21	0.53 ± 0.32	0.102
	Peak eversion torque (Nm/kg)	-0.26 ± 0.05	-0.21 ± 0.11	0.813
	Peak torque of internal rotation (Nm/kg)	0.35 ± 0.07	0.23 ± 0.12	0.093
	Peak torque of external rotation (Nm/kg)	-0.08 ± 0.05	-0.08 ± 0.02	0.611

-2.65 ± 0.38 Nm/kg to -1.48 ± 0.45 Nm/kg and 3.51 ± 0.66 Nm/kg to 2.92 ± 0.57 Nm/kg, respectively ($P < 0.05$). The other peak torques were not significantly changed (Table 4). The results indicated that the peak flexion torque was significantly increased, while the peak extension torque was significantly decreased. Only the peak torque of dorsiflexion and plantar flexion in the ankle joint was significantly changed after training compared to that before training from 0.68 ± 0.54 Nm/kg to 0.93 ± 0.67 Nm/kg ($P < 0.01$) and -3.15 ± 0.32 Nm/kg to -2.47 ± 0.45 Nm/kg ($P < 0.05$). The rest of the peak torque was not significantly changed.

Discussion

The basketball game is widely popular and is characterized by high levels of physical confrontation, which inevitably leads to collisions between players. As a result, the strength and flexibility of the lower limbs play a crucial role in the performance of basketball athletes. Adequate lower-limb strength provides support and explosive power during offensive and defensive transitions and shooting, while flexibility improves movement speed and balance. Rapid extension and contraction training develops muscle strength by using rapid transitions between centrifugal and centripetal contractions. During exercise, it is necessary to have a coach present to provide guidance and prevent improper techniques that could lead to sports injuries. In addition, through sports biomechanics testing, the effects of training can be observed intuitively, and the coach can also guide the intensity or focus of training based on the test results. In this study, 30 players were selected from the college basketball team for the case analysis. The results showed that, after the training, the height that the participants could achieve in the stop jump was significantly improved. Moreover, the vertical and inward reaction forces from the ground during takeoff were also significantly improved. The range of the flexion and extension angle in the hip and knee joints, as well as the range of the dorsiflexion and plantarflexion angle in the ankle joints, were significantly improved during the takeoff stage of the stop jump. The range of angle variation in some lower limb joints such as the hip and knee joints increased after the players underwent rapid extension and contraction compound training. After increasing the change range of these two joint angles, the lower limb muscles were able to function for a longer duration, resulting in greater performance benefits. Moreover, a more extensive range of change could also provide more buffer room after jumps. Reducing the range of the ankle inversion and eversion angle improved foot stability. After the training, the muscle strength of the lower limbs was improved, and the peak torque of the lower limb joints correspondingly changed during jumps. The results of this study confirmed that, after the rapid expansion and contraction compound training, the height of the players' takeoff and the ground reaction force increased significantly. The range of the flexion and extension angle in the hip and knee joints and the range of the dorsiflexion and plantar flexion angle in the ankle joints were also significantly increased. In contrast, the range of the inversion and eversion angle in the ankle joints was significantly decreased during the takeoff stage. The peak flexion torque of the hip joint, the peak flexion torque of the knee joint, and the peak flexion torque of the ankle joint significantly increased too. However, the peak flexion torque of the knee joint and the peak dorsiflexion torque of the ankle joint significantly decreased during the takeoff stage.

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