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ARTICLE

Biomechanical Properties of Multi-Swing and Single-Swing Rope Skipping Actions

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ABSTRACT

Rope skipping is popular as it is easy to learn; thus, it has developed into a competitive sport. The research on the biomechanical properties of rope skipping can effectively improve training efficiency and reduce injury probability. This paper briefly introduced the characteristics of single-swing and multi-swing techniques in competitive rope skipping, selected ten second-grade athletes as the subjects to test the single-swing and triple-swing rope skipping, and tested the biomechanical properties in the process of rope skipping. The results showed that the variation range of the lower limb joint angle in the triple-swing rope skipping was larger than that in the single-swing rope skipping in the stage of thrusting against the ground and the hanging stage and smaller in the buffering stage. The maximum ground reaction force, the maximum vertical displacement, the vertical velocity at the moment of leaving the ground, and the vertical velocity at the moment of landing in triple-swing rope skipping were significantly higher than those in the process of single-swing rope skipping. In conclusion, to ensure the success of the triple-swing rope skipping, the lower limbs need to exert a larger acting force on the ground to obtain larger counter-acting force to extend the hanging time and ensure three circles.

KEYWORDS

Rope skipping; biomechanics; single swing; triple swing

1 Introduction

Rope skipping is a very traditional sport. It only needs a rope of proper length. The requirement of rope skipping for the site is not high, as long as there is no wind and the ground is flat [1]. As the upper limbs and lower limbs need to cooperate in rope skipping, rope skipping attaches great importance to the overall coordination of the body. Moreover, the exercise of rope skipping will also strengthen the coordination of the body. Therefore, rope skipping is selected in the basic training of sports, such as boxing, which emphasizes body coordination [2].

With its simple threshold, rope skipping has developed into an extensive fitness exercise, and fancy rope skipping in a variety of forms has developed [3]. Benefit from the convenience and popularity of rope skipping, many people are keen on rope skipping and fancy rope skipping. Under the influence of the huge population base and the sense of competition, rope skipping has gradually upgraded from folk sports to competitive sports in China and abroad. Rope skipping competitions are held regularly in China and abroad. After rope skipping becomes a competitive sport, corresponding sports guidance will be produced to improve the rope skipping performance of rope skippers [4]. Besides exercising the human body, sports will also damage the human body, so is rope skipping. Periodic take-off movements and rope shaking movements of both arms will burden the corresponding joints. Once the limit is exceeded, it will not only fail to improve the performance but also cause injury to the athletes [5]. The application of the biomechanical analysis method can analyze rope skipping movements more scientifically and logically to find out the movement characteristics of single-swing and multi-swing techniques, thus to realize targeted training of rope skipping skills. Harry et al. [6] studied the biomechanical difference between men and women when they focused on the inside and outside during the vertical jump. The research results showed that both men and women increased the contribution of the knee joint to the energy absorption of lower limbs by focusing on the outside during landing after a vertical jump. Ford et al. [7] simulated targets in reality using a virtual environment with real-time feedback function and tested the biomechanical properties of targets above the ground in real and virtual environments during jumping. The results showed that virtual simulation could optimize the jumping height and promote increased hip moments and trunk flexion and could be an alternative in some biomechanical tests. The literature mentioned above have all studied the biomechanics of rope skippers in the process of rope skipping, but only studied the biomechanical properties of single jump. In addition to single-swing jump, triple-swing jump is also a kind of competitive rope skipping. Therefore, this study analyzed not only the biomechanical properties of single-swing jump but also the biomechanics of triple-swing jump. This paper briefly introduced the characteristics of single-swing and multi-swing techniques in competitive rope skipping, selected ten second-grade sportsmen from Sichuan University of Science and Engineering as the subjects for the single-swing and triple-swing rope skipping tests, and tested the biomechanical properties in the process of rope skipping. Rope skipping requires the cooperation of upper limbs and lower limbs. To increase the fault tolerance rate in the process of rope skipping, the lower limbs need to cooperate with the upper limbs' rope swing speed in the process of thrust against the ground to extend the hanging time, especially in the triple swing rope skipping. To realize three circles of rope swing in one jump, enough hanging time is needed. Research on the biomechanical performance of rope skippers in the process of rope skipping can effectively understand the joint changes of lower limbs in the process of single swing and triple swing, as well as the changes of ground force and speed, to summarize the variation rules and provide an effective data reference for rope skipping training schemes. Paying attention to the lower limb joint transformation can effectively help correct the wrong posture of athletes and reduce the probability of injuries. Therefore, applying the results of the study to the training of rope skipping athletes can effectively improve the training effect.

2 Experimental Test

2.1 Experimental Subjects

The purpose of this study is to study the biomechanical properties of rope skippers in single-swing and triple-swing rope skipping to provide an effective reference for rope skipping training. Finally, ten male athletes from Sichuan University of Science and Engineering were selected as the experimental subjects, and their basic information is shown in Tab. 1. The average height of the ten athletes was 175 ± 5 cm, and their average weight was 75 ± 5 kg. The average age of the ten athletes was 20 ± 2 years old. Their average training time for rope skipping events was 3 ± 1 years. The subjects had no history of injury, and their limbs were not injured in the first three months before the test. The subjects received the single-swing and triple-swing tests in a healthy state.

Table 1: The basic data of experimental subjects

Height/cm	Weight/kg	Age/year	Training time/year	Injury history	Whether there is limb damage in recent three months
175 ± 5	75 ± 5	20 ± 2	3 ± 1	None	None

2.2 Experimental Content

The biomechanical performance analysis methods for the single-swing and triple-swing rope skipping include the literature review method, expert interview method [8], and experimental method. The literature review method mainly refers to reviewing the relevant literature about rope skipping and the application of biomechanics in sports activities to understand the relationship between rope skipping and biomechanics. The expert interview method is to consult relevant experts and biomechanical experts and design and adjust the research methods according to their suggestions. The experimental method analyzes the biomechanical performance by measuring the movement changes of limbs and trunk in the process of single-swing and multi-swing rope skipping by corresponding devices.

2.2.1 Experimental Apparatus

The biomechanical properties of rope skipping were studied using the experimental method. The test instruments needed in the experiment included a high-speed camera, three-dimensional force platform, skipping rope, metronome [9], etc., of which the high-speed camera was FASTCAM Nova S12, with the maximum full-frame shooting speed of 12800 frames/s, and the sampling frequency in the experiment was 60 Hz. The model number of the three-dimensional force measuring platform was 9281CA (Kistler company, Switzerland). The force in three axial directions in the three-dimensional coordinate system was measured by the built-in piezoelectric sensor, with a sampling frequency of 1000 Hz. The material of the skipping rope was PVC plastic, with a length of 2 m and a diameter of 0.5 cm.

2.2.2 Test Action

As shown in Fig. 1, the action adopted in the rope skipping test was the forward rope skipping with two feet together. Whether it was single-swing or multi-swing, one cycle was divided into three stages: The stage of thrusting against the ground, the hanging stage, and the buffering stage. The stage of thrusting against the ground [10] was from the moment when the top of the head was at the lowest level to the moment that the feet left the ground. The hanging stage was from the moment when the stage of thrusting against the ground ended to the moment when the feet contacted the ground. The buffering stage was from the end of the hanging stage to the moment when the top of the head dropped to the lowest point. The difference between the single-swing and multi-swing rope skipping was that the single-swing rope skipping needed to make the rope pass below the foot once in the hanging stage, while the multi-swing rope skipping needed to pass multiple times, which was three times in this study.

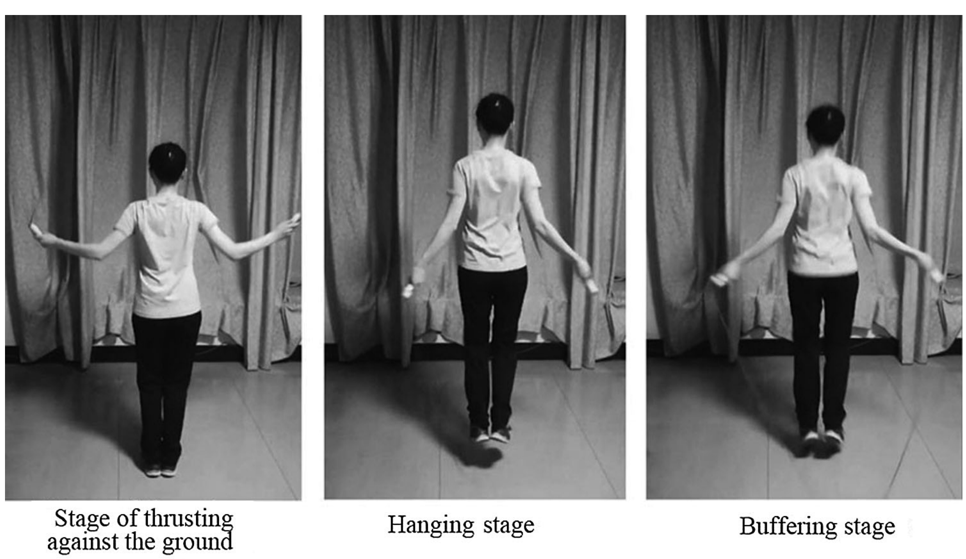

Figure 1: Three stages in the process of the single-swing and multi-swing rope skipping

2.2.3 Test Items

Firstly, a test platform was built by using eight high-speed cameras and a three-dimensional force measuring platform. As shown in Fig. 2, the eight cameras surrounded the three-dimensional force measuring platform. Every lens was aligned with the center of the force measuring platform. The horizontal distance between the lens and the center of the force measuring platform was 2.5 m. The basic actions during the test are as described above. To prevent injury during the rope skipping experiment, a warm-up exercise [11] was conducted before the formal test, including 15 min jogging and *in situ* vertical jump and squat jump for ten times, respectively, after 5 min of rest. After 5 min of rest, the rope skipping test started.

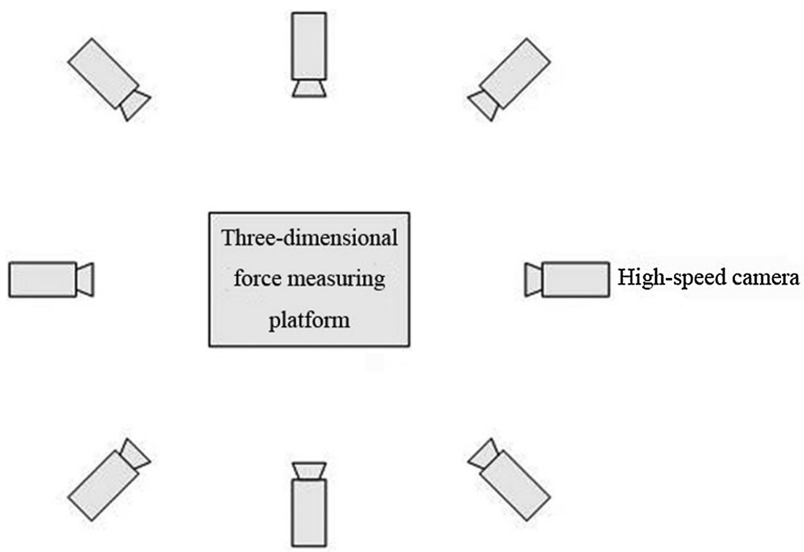

Figure 2: The setting mode of the high-speed cameras and three-dimensional force measuring platform

Each athlete was tested in the center of the three-dimensional force platform for the single-swing and triple-swing rope skipping. The speed of the single-swing rope skipping was set was 60 times/min after the test of uniform trial jump; the speed of the triple-swing rope skipping was set as 20 times/min. The above rope skipping speed was controlled by the rhythm of the sound produced by the metronome. The difference in the times between the single-swing and triple-swing rope skipping was because only one triple swing was counted as one time. In this study, to ensure the comparability of the test results between the single-swing and triple-swing rope skipping and the reliability of the comparison, the times of the rope passing below the feet within the same time was consistent, although the count of skipping under the high speed and low speed was different.

The single-swing and multi-swing rope skipping had some exercise intensity no matter the speed was high or low. Although the speed of rope skipping could be controlled by the metronome, it was difficult to ensure the uniform jump in the later period in the long-term movement process, which impacted the biomechanical performance analysis. Therefore, whether it was fast or slow, the single-swing rope skipping test lasted for 15 s.

2.3 Mathematical Statistics

In this study, the moving images of rope skipping were captured by the high-speed camera, and the changes of the lower limb joint angle of athletes were collected. The stress of the lower limbs was collected by using the three-dimensional force measuring platform. The collected data were analyzed by

Excel and SPSS software [12]. The average value of the statistic data was expressed in the form of $x \pm s$. The difference between the single swing and triple swing was determined based on the p-value.

2.4 Experimental Results

In the test process, the angle changes of the lower limb joints in the three stages of the single-swing and triple-swing rope skipping are shown in Figs. 3–5. As the introduction of skills of single-swing and triple-swing rope skipping above, a complete single-swing or triple-swing rope skipping could be divided into three technical stages. Although the test time of all athletes was 15 s, the time required to complete each technical stage was different due to the different quality of each player, which was not conducive to comparative analysis. Therefore, the time used in each technical stage was set as 1, and the time was divided in the form of a percentage. It was seen from Figs. 3–5 that the angle change trend of the hip, knee, and ankle joints was nearly the same in the whole process of single-swing rope skipping, i.e., rising in the stage of thrusting against the ground, stable in the hanging stage, and decreasing in the buffering stage; the changing trend of angles in the whole process of the three-swing rope skipping was similar, i.e., rising in the stage of thrusting against the ground, decreasing first and then increasing in the hanging stage, and decreasing in the buffering stage.

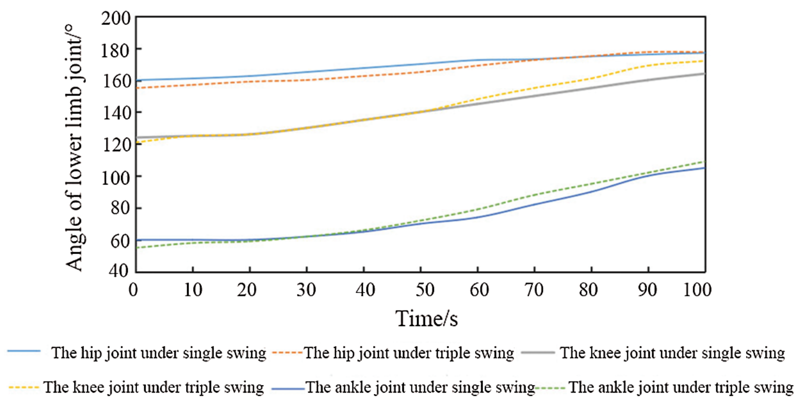

Figure 3: Angle changes of lower limb joints in the single-swing and triple-swing rope skipping in the stage of thrusting against the ground

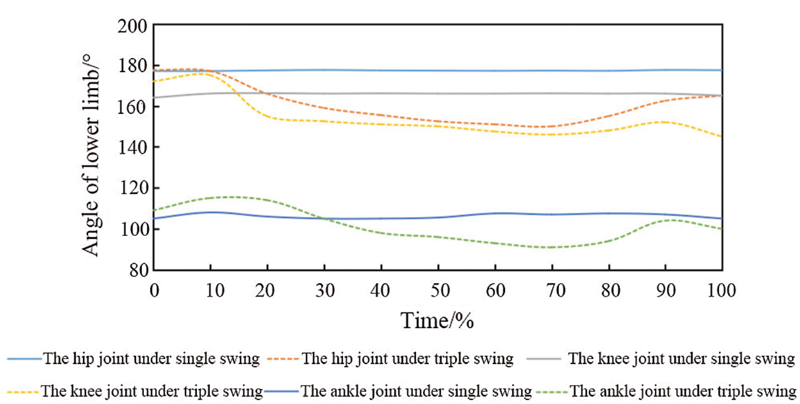

Figure 4: Angle changes of lower limb joints in the single-swing and triple-swing rope skipping in the hanging stage

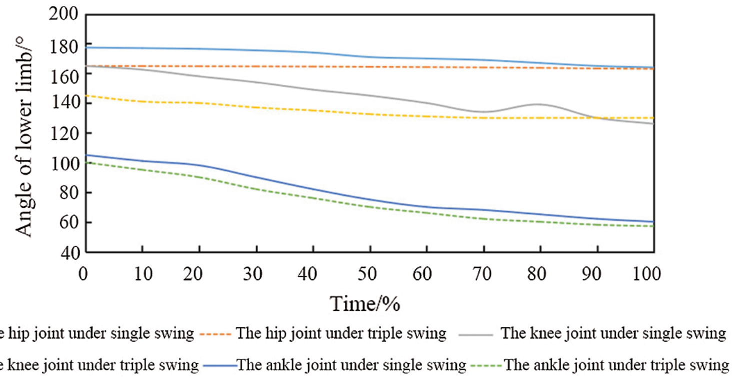

Figure 5: Angle changes of lower limb joints in the single-swing and triple-swing rope skipping in the buffering stage

The motion ranges of hip, knee, and ankle joint angles and the peak value of joint torque in the three technical stages are shown in Tab. 2. The comparison of the data in Tab. 2 shows that the angle variation amplitudes of the hip, knee, and ankle joints caused by the triple-swing rope skipping were significantly higher than those of the single-swing rope skipping in the stage of thrusting against the ground; in the hanging stage, the variation amplitude of lower limb joints in the triple-swing rope skipping was greater, and that in the single-swing rope skipping was very small; in the buffering stage, the variation amplitude of lower limb joints was smaller in the triple-swing rope skipping. In the process of the single-swing and triple-swing rope skipping, the peak torque of lower limb joints changed, but the difference was not obvious.

Table 2: Kinematic parameters of lower limb joints in three stages of the single-swing and triple-swing rope skipping

Stage	The stage of thrusting against the ground			The hanging stage			The buffering stage		
Type	Single swing	Triple swing	*p*-value	Single swing	Triple swing	*p*-value	Single swing	Triple swing	*p*-value
Motion range of hip joint/°	17.55 ± 1.23	22.55 ± 1.21*	0.021	1.12 ± 0.23	27.55 ± 1.11*	0.015	13.41 ± 1.01	2.02 ± 0.23*	0.022
Peak torque of hip joint Nm/kg	1.84 ± 1.11	1.85 ± 1.12	0.064	1.86 ± 1.11	1.84 ± 1.14	0.067	1.86 ± 1.11	1.85 ± 1.21	0.074
Motion range of knee joint/°	39.11 ± 1.32	50.21 ± 1.87*	0.014	40.12 ± 1.11	51.21 ± 1.12*	0.021	39.23 ± 1.11	15.26 ± 1.14*	0.013
Peak torque of knee joint Nm/kg	1.44 ± 1.21	1.45 ± 1.32	0.059	1.44 ± 1.21	1.46 ± 1.11	0.064	1.42 ± 1.11	1.44 ± 1.12	0.067
Motion range of ankle joint/°	45.23 ± 1.25	55.36 ± 1.24*	0.015	3.12 ± 0.52	23.41 ± 1.01*	0.024	45.32 ± 1.21	43.25 ± 1.11*	0.023
Peak torque of ankle joint Nm/kg	0.034 ± 0.01	0.032 ± 0.01	0.077	0.033 ± 0.01	0.031 ± 0.00	0.074	0.032 ± 0.02	0.031 ± 0.00	0.075

Note: * indicates that *p*-value is smaller than 0.05, i.e., the difference between the single swing and triple swing is obvious.

The ground reaction force changes of the single-swing and triple-swing rope skipping in the stage of thrusting against the ground and the hanging stage are shown in Figs. 6 and 7. In the hanging stage, as the athlete did not contact the ground, there was no ground reaction force in this stage; the reaction force curve change in this stage was not shown. It was seen from Fig. 6 that the reaction force suffered by the athletes showed a downward trend in the stage of thrusting against the ground, whether it was single swing or triple swing, but on the whole, the initial reaction force of the triple-swing rope skipping was significantly higher, and the decrease was faster. It was seen from Fig. 7 that the reaction force in the single-swing and triple-swing rope skipping showed an increasing trend in the buffering stage, and the reaction force of the triple-swing rope skipping increased faster and was larger. Tab. 3 shows the dynamic parameters of athletes in the process of the single-swing and triple-swing rope skipping. The comparison between the single-swing and triple-swing rope skipping showed that the maximum ground reaction force, maximum vertical displacement, the vertical velocity at the moment of leaving the ground, and vertical speed at the moment of landing in the triple-swing rope skipping were significantly higher than those in the single-swing rope skipping in the whole rope skipping process.

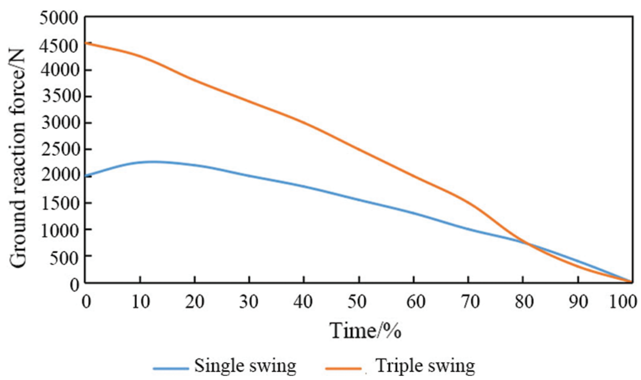

Figure 6: Ground reaction force of the single-swing and triple-swing rope skipping in the stage of thrusting against the ground

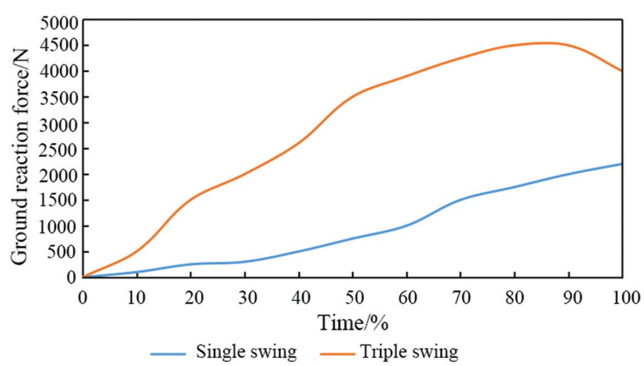

Figure 7: Ground reaction force of the single-swing and triple-swing rope skipping in the buffering stage

Table 3: Dynamic parameters in the process of single-swing and triple-swing rope skipping

	Single swing	Triple swing	*p*-value
Maximum ground reaction force (n)	2011 ± 11	4510 ± 13*	0.032
Maximum vertical displacement (cm)	5.23 ± 1.21	15.34 ± 1.11*	0.023
Vertical velocity at the moment of leaving the ground (m/s)	0.18 ± 0.03	0.98 ± 0.01*	0.021
Vertical velocity at the moment of landing (m/s)	−0.65 ± 0.12	−1.42 ± 0.11*	0.031

Note: * indicates that *p*-value is smaller than 0.05.

3 Discussion

Although rope skipping is easy to learn, it can exercise the human body. The tool for rope skipping is easy to get, and its requirement for site is not high. Rope skipping, a popular recreational sport, also has world-wide competitive competitions. It is very important for athletes to improve their performance by training. However, the change of body structure in rope skipping has rules. Although it can be improved by simply relying on hard training, the improvement is limited, and the nonstandard posture will increase physical burdens, which is not conducive to future development. Rope skipping athletes need a set of scientific training scheme with data support in training to improve the performance of rope skipping and ensure the safety of the body.

In this study, the biomechanical properties of rope skippers were analyzed by taking the single-swing and three-swing events as the subjects. The final test results are as shown above, and the results are briefly analyzed here.

In the stage of thrusting against the ground, the variation tendency of the hip joint was nearly consistent in single-swing and triple-swing events; at the last moment of this stage, the angle of the joint was close to 180°. In this stage, the variation of the hip joint angle in the triple swing was significantly larger than that in the single swing. The above results showed that the body and legs would extend in both single swing and triple swing in the stage of thrusting against the ground. When the athlete jumped up, the difference between single swing and triple swing in the change of the angle was because triple swing needed more hanging time, i.e., more significant change in the stage of thrusting against the ground, to obtain enough acceleration time. The variation tendency of the knee joint was nearly consistent, but the angle of the knee joint in the triple swing was larger than that in the single swing at the last moment of this stage. Moreover, the variation amplitude of the knee joint in the triple swing was larger than that in the single swing in the whole stage, which was because the lower limbs needed to obtain a larger force when thrusting against the ground.

In the hanging stage, the comparative analysis on lower limb joints showed that the angle variation of lower limb joints had a significant difference between single swing and triple swing in the hanging stage. The joint change of the lower limbs in the single swing was stable, but the change in the triple swing was significant, decreasing firstly and then increasing. The change of the angles demonstrated that the shrinking of the body was more significant in the hanging stage of triple swing, which was because shrinking the body could increase the hanging height. The decrease of the angles was to extend the body to reduce landing injuries.

In the buffering stage, the comparative analysis on the lower limb joints showed that the angle variation tendency of lower limb joints was nearly consistent. The figure and table showed that the variation of joint angles of triple swing was smaller than that of single swing in the buffering stage. In the hanging stage, to ensure enough hanging time, the athlete shrank the body in the triple swing. The body has been extended a little to ensure safety when landing, but the extension was not complete in a short time, leading to the small change in joint angles.

4 Conclusion

This paper briefly introduced the characteristics of single-swing and multi-swing techniques in competitive rope skipping, selected ten athletes from Sichuan University of Science and Engineering for the single-swing and triple-swing rope skipping tests, and tested the biomechanical properties in the process of rope skipping. The results are as follows. (1) The variation amplitude of lower limb joint angles was larger in the process of triple-swing rope skipping than that in the single-swing rope skipping in the stage of thrusting against the ground and the hanging stage, and was smaller in the buffering stage; the peak value of lower limb joint torque had no significant difference. (2) The maximum ground reaction force, the maximum vertical displacement, the vertical velocity at the moment of leaving the ground, and the vertical velocity at the moment of landing in the triple-swing rope skipping were significantly higher than those in the single-swing rope skipping. The shortcomings of this study were that the research subjects were all males and only the changes of the lower limbs were tested in the biomechanical test. Future research involves female athletes and movement changes of upper limbs.

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Conflicts of Interest: The authors declares that she has no conflicts of interest to report regarding the present study.

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