Biomechanical Characteristics Analysis of Highly Difficult Movements “324C+1D” in Competitive Wushu Routine

Xikui Guo

A Thesis Submitted in Partial Fulfillment of Requirements for degree of Doctor of Philosophy in Exercise and Sport Science

June 2024

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The examining committee has unanimously approved this Thesis, submitted by Mr. Xikui Guo , as a partial fulfillment of the requirements for the Doctor of Philosophy Exercise and Sport Science at Mahasarakham University

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ABSTRACT

One of the main purposes of biomechanics in the study of sports technology is to reveal the principles of sports technology, especially in the field of competitive sports. The principles and methods of sports biomechanics are the main means to analyze and diagnose the technical characteristics of athletes, and also the main methods to improve sports performance, explore technical rules and improve sports skills. In the competitive wushu routine competition, martial arts difficult movement plays an important role in the Wushu routine competition, the level, type and quantity of martial arts difficult movement is an important factor reflecting the quality of the choreography of martial arts complete sets of movements, the training level of athletes and the guidance level of coaches. "324C+1D" movement is one of the highest points in martial arts difficult movements, is the key movement to show the level of athletes' competitive ability, and plays a key role in the victory of athletes in the competition. Using biomechanical test method to study the biomechanical characteristics of "324C+1D" movement is very important for guiding training.

The purpose of this research is three: (1) to test the difficult movement "324C+1D" completed by national wushu athletes and analyze the biomechanical characteristics of this movement; (2) Test the difficult movement "324C+1D" completed by the first-level martial arts athletes, and analyze the biomechanical characteristics of the movement; (3) Compare the biomechanical characteristics of national and first-level martial arts athletes in completing difficult movements "324C+1D".

Six male athletes from Shaanxi Martial Arts team participated in this study, including 3 national martial arts athletes and 3 first-level martial arts athletes, aged 16-25 years old, able to skillfully complete the difficult movement "324C+1D". Wushu athletes involved in this study have won the national Wushu competition champion many times, and their sports level represents the highest level of Chinese wushu. It is of great application value to study the biomechanical characteristics of the difficult martial arts movement.

This study adopts the method of literature, testing and mathematical statistics to study the sports biomechanical characteristics of "324C+1D", a difficult movement of competitive martial arts routine. The "324C+1D" movements of national wushu athletes and first-class wushu athletes were tested by 3D high-speed photography, 3D force measurement and wireless surface electromyography. The kinematic data, force value and surface EMG data obtained from the test were selected, and the selected values were analyzed for data such as mean value, standard deviation and T-test. The biomechanical characteristics of the martial arts difficult movement "324C+1D" were divided into four stages, namely, run-up, take-off, flying and landing. This paper analyzes and summarizes the technical characteristics of national wushu athletes completing "324C+1D" movements and the technical characteristics of first-level wushu athletes completing "324C+1D" movements. The technical characteristics of "324C+1D" movements of national wushu athletes and first class wushu athletes are compared and analyzed. Combined with the theory of sports biomechanics, this paper discusses the factors of sports technique that affect athletes to complete "324C+1D" movement. The main conclusions are as follows:

(1) The factors affecting the lifting distance of the "324C+1D" action are: Speed of run-up and take-off, center of gravity lifting Angle, ground reaction force during take-off push and extension, center of gravity height at the time of leaving the ground, Angle and speed of swinging arms and legs before lifting, etc., the lifting distance in the air is the basis and premise for athletes to complete difficult actions, and when reaching a certain range, it is not the key to the completion of "324C+1D" action.

(2) The factors that affect the rotation Angle of "324C+1D" movement are: the Angle and speed of swinging arms and legs before flying, the twisting Angle of shoulders and feet when leaving the ground and landing, the falling distance in the air, the speed of swinging legs in the air and the control of body posture, etc. Rotation Angle is the key for athletes to complete difficult movements.

(3) The factors affecting the landing connection of "324C+1D" action are: landing buffer distance, landing shoulder and foot torsion Angle, landing ground reaction force, etc.

(4) There is no significant difference between the sports biomechanical characteristics of National athletes and First-class athletes in completing "324C+1D" movements.

Keyword : Biomechanical characteristics, Competitive Wushu Routine, Difficult movements "324C+1D"

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Xikui Guo

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CHAPTER I

INTRODUCTION

Background

Sports biomechanics is a discipline that applies the knowledge of biology and the principles and methods of physics and mechanics to study the movement laws of human body (or equipment) in sports. In the study of sports technology, one of its main purposes is to reveal the principles of movement technology, especially in the field of competitive sports. The principles and methods of sports biomechanics are the main means to analyze and diagnose the technical and tactical characteristics of athletes, as well as the main methods to improve sports performance, explore technical rules, and improve motor skills and tactics (Zhang, 2012).With the development of science and technology, the high-end instruments and equipment are more advanced, and the sports biomechanics testing means are more diverse, which makes the sports technology has been greatly improved. At present, sports techniques and tactics are analyzed using video analysis, high-speed photography, sensor measurement, infrared high-speed motion capture system, laser tester, 3D force measuring table, etc., mainly focusing on 2D and 3D video analysis of technical movements, and combining a variety of sports biomechanical testing means to analyze technical movements have also emerged. In track and field, taekwondo, tennis, table tennis and other events, two-dimensional and three-dimensional video analysis method is used for quantitative analysis of technical movements, to find the advantages and disadvantages of movement techniques, and to provide a basis for improving sports training and performance. The rapid development of sports biomechanics research methods and instruments provides a platform for the improvement of various sports techniques. In practice, research on the technical principles of various sports requires sports biomechanics, which can be used as a theoretical index for the technical judgment of movements and the improvement of training methods (Zhao, 2022).With the development of science and technology, the research methods of sports biomechanics have been constantly innovated, the level of measurement technology has been gradually improved, and the research of various sports techniques has been continuously deepened, thus promoting the improvement of the technical level of various sports and sports achievements, and wushu projects will certainly benefit from it. By studying the application status of sports biomechanics in Wushu movement technology analysis, we found that Wushu researchers have not introduced advanced sports biomechanics research methods and equipment into the analysis of movement technology, and there is a large space for utilization and development (Yang & Yang, 2006).

In recent years, with the popularity and promotion of competitive wushu events in the country, wushu competitions at all levels in the country have also been rapidly developed, which greatly drives the participation of wushu lovers and wushu students in colleges and universities, and to a certain extent promotes the development of competitive wushu. Throughout the competitions of various competitive wushu events, it can be clearly found that in the national top wushu competitions, the competitive level and professional basic skills of the athletes in the same team are similar, and at this time, "the selection of difficult wushu movements and routine arrangement have a significant impact on the final performance and ranking of the athletes" (Sun,2012). High difficulty jumping plays an important role in wushu competitive routines. According to the rules of competition wushu routine, the total score of each event is 10 points, including 5 points for movement quality, 3 points for drill level and 2 points for movement difficulty. Among the 2 points of action difficulty, 1.4 points of action difficulty, 0.6 points of connection difficulty and additional points of innovation difficulty are included. Action difficulty includes balance, leg method, jumping and diving. And according to the grade: A action (each action score 0.2), B action (each action score 0.3), C action (each action score 0.4).

According to the results of the National Routine Championship in 2003, "movement difficulty" and "connection difficulty" are highly positively correlated with the performance of the competition, and the completion degree and score of "movement difficulty" and "connection difficulty" directly affect the performance of the athletes (Li, 2011).Wushu difficult movements play a vital role in the competition of Wushu routine, and the rules of Wushu competition are constantly innovated with the continuous development of Wushu. Wushu difficult movements have different contents and characteristics in different periods, and the continuous development of competitive Wushu in the new period adds many new active elements to Wushu, and makes the requirements of technical movements higher. In competitive wushu routine competition, the level, type and number of Wushu difficult movements are important factors that reflect the quality of the choreography of the whole set of Wushu movements, the athletes' training level and the coaches' guidance level. In the competitive wushu routine sports competition, the difficult movement is the climax of the whole movement. Among them, the difficulty movements are mainly composed of various levels in the balance, leg method and jumping class. The frequency of the connecting difficulty movements in the order from more to less is falling and vertical fork, horse step and foot step, which are the essence part of the difficulty movements of the Wushu routine. The success rate and failure rate of the completion of this series of difficult movements directly determines the final performance of the athletes. Thus, in competitive Wushu, "the choice of difficult movements in Wushu is closely related to the future and development of individual athletes and the entire team" (Li, 2011).

High difficulty jumping is one of the main winning abilities of competitive wushu routines. The athletic performance is the essential factor for the survival and development of competitive athletes, coaches and teams, and also the core of competitive sports. Many experts and scholars have summarized the winning elements of competitive Wushu routine as "high, difficult, new, beautiful and stable", and endowed the technical connotation of "high, difficult, new, beautiful and stable". These technical connotations have different emphasis and mutual support (Luan et al.,2005).A large number of literature studies have shown that the completion of difficult jumps, such as "324C+1D" directly determines the performance of athletes in competitive Wushu routines, which can be regarded as the key techniques integrating winning factors of "high, difficult, new, beautiful and stable" (Xiong, 2007).

Recognizing the biomechanical characteristics of difficult movements is an important premise for athletes to master difficult movements in competitive wushu routines. It is urgent to sum up the biomechanical characteristics of athletes completing difficult movements in competitive Wushu routine to enrich and develop the training theory of competitive Wushu routine. It is the only way to improve the training efficiency and the performance of competitive wushu routine athletes. The jump of 324C (720°) +1D (horse step) is the most difficult "movement + connection" in Wushu competition, and its score is 0.65. The smooth completion of this movement not only reflects the athlete's superb level, but also helps the athlete to achieve good results in the competition.

The whole process of difficult movements of wushu routine is very complicated. The current training practice is mainly guided by experience. Although there have been researches on airborne rotational motion in recent years, most researches only use a single research method to measure and analyze the kinematics of airborne rotational motion and describe the airborne rotational motion (Wei, 2015).

Through combing the relevant literature, it is found that, as a key technique in gymnastics, aerobics, Wushu routines, figure skating, skiing and other difficult sports, scholars have paid extensive attention to and conducted a lot of research. The main research methods include video observation, 3D video analysis, infrared high-speed motion capture, 3D force measurement and surface electromyography test. At present, there are few studies on surface electromyography of the difficult movement "324C+1D" in wushu routine. The kinematic, dynamic and surface EMG indexes selected by each project in the test and analysis are relatively similar. The commonly used kinematic indexes are: height of gravity, distance of center of gravity, center of gravity, horizontal velocity, center of gravity, vertical velocity, center of gravity lifting Angle, rotational angular velocity, air time, etc. The kinetic index is: ground reaction force value; Surface EMG indexes include muscle activation time sequence, integrated EMG value, median EMG frequency signal, etc.

In the past, the testing techniques of competitive Wushu routine limited the deep research on the movement techniques of competitive Wushu routine. The lag of the theoretical research of competitive Wushu routine restrains the mastery and development of high and difficult movements of competitive Wushu routine. The innovation and optimization of high and difficult movement technique training means of competitive Wushu routine urgently need the support of theoretical research. The lack of research on the difficult movements of competitive Wushu routine affects the teaching and training practice of competitive Wushu routine. At present, it is the requirement of scientific training to use the method of sports biomechanics to analyze the characteristics of the most difficult movements in Wushu routine and apply the research results to the training of athletes.

Objectives

(1) To test the difficult movement "324C+1D" of competitive Wushu routine completed by wushu athletes at national level, and analyze the biomechanical characteristics of this movement;

(2) To test the difficult movement "324C+1D" of competitive Wushu routine completed by Wushu athletes at first level, and analyze the biomechanical characteristics of this movement;

(3) To compare the biomechanical characteristics of the difficult movement "324C+1D" of competitive Wushu routine completed by Wushu athletes at national level and first level.

Hypothesis of the Research

(1) The difficulty movement "324C+1D" of the competitive Wushu routine completed by the national level Wushu athletes shows obvious biomechanical characteristics.

(2) The difficulty movement "324C+1D" of the competitive Wushu routine completed by the First level Wushu athletes shows obvious biomechanical characteristics.

(3) There is a significant difference between the biomechanical characteristics of "324C+1D", the difficulty movements of competitive Wushu routine completed by national level Wushu athletes and those completed by first-level Wushu athletes.

Significant of Study

Theoretical Significance

(1) Break through the defects of previous studies, and summarize the biomechanical characteristics and movement rules of competitive Wushu routine athletes when they complete difficult movements.

(2) It enriches and improves the biomechanical characteristic system of competitive Wushu routine athletes when they complete difficult movements, and provides theoretical guidance for the scientific training of competitive Wushu routine athletes.

Practical Significance

(1) Coaches of competitive martial arts routines can use the biomechanical characteristics of difficult movements "324C+1D" to design training programs to improve the athletic performance of athletes completing difficult movements "324C+1D".

(2) Athletes of competitive martial arts routines can use the biomechanical characteristics of the difficult movement "324C+1D" and their experience gained in training to improve the training effect and improve the success rate of completing the difficult movement "324C+1D".

(3) On the basis of this study, researchers can avoid the shortcomings of this study, do further research, and develop and improve more biomechanical research of motor movements.

Related concepts and definitions

1. Biomechanics

Biomechanics is a branch of biophysics that applies the principles and methods of mechanics to the quantitative study of mechanical problems in living organisms. The research scope ranges from the whole organism to the system and organ (including blood, body fluid, viscera, bone, etc.), from bird flight, fish swim, flagella and cilia movement to the transport of plant body fluid, etc（Yan，2012）.

2. Sports Biomechanics

The concept of sports biomechanics is the science of studying the movement law of human body and apparatus in sports（Yan，2012）.

3. Competitive Wushu Routine

A competitive sports event composed of movements with the meaning of attack and defense, with competitive competition as its main feature and with the main goal of creating excellent sports results and winning games as a complete set of exercises. It is the product of the modernization development of Chinese Wushu. As the intersection of Wushu routines and competitive sports, it has obvious national traditional characteristics and modern competitive sports characteristics (Luan et al., 2005).

4. Vertical rotation in the air

In the 2012 edition of Wushu routine competition rules, the code is divided according to the body state in the jumping movement, including: upright, vertical turn, sagittal turn, frontal turn, double turn and rotation. In the jumping class, the secondary code of the vertical turn is "2", such as: Whirlwind foot, Jumping spin lotus kick, swing foot inward turn, etc. Based on this, the jumping movement rotating along the vertical axis is defined as the technical movement of vertical rotation in the air, and the technical characteristics and related sports quality training are studied by taking the Jumping spin lotus kick as an example.

5. 324C+1D

"324C+1D" is the secondary code of the movement combination consisting of Jumping spin lotus kick 720°(324C) -- the most difficult movement of the Wushu routine and the most difficult connecting movement horse step (+1D).

Description of the action process of “324C+1D"：The "324C+1D" action consists of four technical links: run-up, take-off, take-off and landing. According to the rules of wushu routine competition, the run-up is required to be within 4 steps, the body runs straight ahead during the run-up, and the feet land parallel at the end of the last step of the run-up. After landing, the legs (ankle bending, knee bending, hip bending) cushion squat, while the torso turns left and the arm is placed on the lower left. Then the legs (ankle extension, knee extension, hip extension) complete the push and stretch movement, while the arm swings from the left bottom direction to the right back and above and turn right with the torso. After leaving the ground, the right leg swings from the bottom to the outside and above. When the leg swings to the front of the body, the left hand and the right foot hit the instep, the right leg presses down after the pat, and the landing connects the horse step.

6. Definition of relevant technical parameters and indicators

Hip Angle: refers to the Angle between the line from the acromion to the center of the hip joint and the line from the center of the hip joint to the center of the knee joint.

Knee Angle: refers to the Angle formed by the center of the ipsilateral hip joint, the line to the center of the knee joint, and the line from the center of the knee joint to the center of the bare joint.

Ankle Angle: refers to the Angle formed by the line from the center of the ipsilateral knee joint to the center of the ankle joint and the line from the heel to the toe.

Center of gravity lifting Angle: refers to the Angle between center of gravity velocity and horizontal plane at the moment of lifting off the ground.

Torsional Angle of shoulder and hip: It refers to the Angle formed by the projection of the two acromial lines and the two central lines of hip joints on the horizontal plane. The index of shoulder-hip torsional Angle selected in this study is: the peak value of shoulder-hip torsional Angle at the take-off stage of the difficult movement "324C+1D”.

Shoulder and foot torsion Angle: Refers to the Angle formed by the projection of the two acromial lines and the two treading joint center lines on the horizontal plane.

Rotational angular velocity of the acromion: refers to the projection of two acromion lines on the horizontal plane and the rotational Angle within unit time (s). This index mainly reflects the rotational angular velocity of the trunk around the vertical axis. The indexes of rotational angular velocity of the shoulder shaft selected in this study are: rotational angular velocity of the shoulder shaft at the moment of striking in the air stage of the difficult movement "324C+1D", peak rotational angular velocity of the shoulder shaft after striking and rotational angular velocity of the shoulder shaft at the moment of landing.

Swing arm speed: In this study, the motion speed of the wrist joint was used to represent the swing arm speed. Selected swing arm speed measure is: the difficult movement "324C+1D" peak action in the take-off phase of the swing arm speed.

Swing leg speed: In this study, the motion speed of the pointe point represents the swing leg speed. The selected index of leg swing speed is: the right leg swing speed in the air stage of the difficult movement "324C+1D". •

Joint sector Angle: is the range of Angle change of the knuckle. The index of joint fan Angle selected in this study is: the knee fan Angle in the landing stage of difficult movement "324C+1D".

Horizontal movement distance of the center of gravity: Refers to the movement distance of the center of gravity of the human body on the horizontal plane. The horizontal moving distance of the center of gravity selected in this study is as follows: the horizontal moving distance of the center of gravity in the airborne stage of the difficult movement "324C+1D".

Vertical movement distance: Refers to the movement distance of the center of gravity of the human body on the vertical axis. The vertical movement distance index of the center of gravity selected in this study is: the vertical movement distance of the center of gravity in the take-off stage, the take-off stage and the landing stage of the pendulums in the air. The take-off stage includes the lifting distance of the center of gravity and the falling distance of the center of gravity.

Surface reaction force value: It's the amount of ground reaction the body is subjected to. The reaction force value index selected in this study is: the peak value of the ground vertical reaction force during the take-off, push and extension stage of the air pendulum movement. This index is expressed by the ratio of the measured force value to the athlete's Body Weight, in BW (Body Weight).

Integral Emg value: refers to the integral of the Emg amplitude in the surface Emg signal generated when the muscle completes the action, reflecting the degree of force when the muscle completes the action.

CHAPTER II

REVIEW OF RELATED LITERATURE

During the past year, I mainly used the Internet such as www.cnki.net, bbs.chinatopfit.com and Baidu Academic. The research literature and related materials of wushu routine jumping movement, aerial turning movement, wushu routine sports quality training, Wushu routine jumping difficulty training, related concepts of sports quality, core strength training, rapid telescopic complex training and so on were searched. Watch the video of the preliminary competition of Wushu routine in the 17th National Games and check the competition rules of Wushu routine in 2012 edition; Read books related to sports anatomy, sports physiology, sports biomechanics and sports training to provide referable materials and theoretical basis for the topic selection and writing of this study.

Theoretical

1. The sequence principle of muscle activity

This principle is also known as the principle of the sum of internal forces, the principle of continuous activity and the principle of angular momentum transfer along the chain of motion. The principle points out how the body can mobilize all parts of the body to participate in the movement at the right time. The large muscle groups, usually the penniform muscles, work first. These muscles contract to overcome the inertia of the whole body and parts of the body. The muscles then work in turn until the fast muscle activity at the end of the limb ends. These activities not only increase the range and speed of motion, but also increase accuracy due to the gradual decrease in the number of muscle fibers innervated by each motor neuron; The sequence of movements of the proximal link before the distal link also ensures that the distal link muscles are moderately elongated before contracting.

Therefore, wushu sports should follow the principle of large joints before small joints, such as in Sanda flagellate leg, waist first activity, then hip, thigh, calf activity in turn; In the basic skills of Nanquan, the waist moves first, such as the horse step, the lunge and the kirin step. Sanda swinging boxing also requires the waist to move first, in turn to the shoulder joint, elbow joint, wrist joint.

2. Principle of minimizing moment of inertia

The rotation of human body includes the rotation of partial body limbs that pull bones around the joint axis under the action of muscle force and the rotation of the whole body (Wang ＆ Li, 2004). The fixed-axis rotation theorem of rigid body ∑ M=I∑(M is torque, ∑ is angular acceleration, I is moment of inertia) (Chi ＆Du, 1996), the muscle force of human body is limited, so the torque of muscle force on a certain axis is also limited, when the muscle torque is certain, reducing the moment of inertia I of the limb can increase the angular acceleration of rotation, thus increasing the angular velocity of rotation; In addition, according to the moment of momentum theorem ∫Mdt=∫d(Iw) or ∑M△t=I(t)wt-I(t0)w0 (I (t) is the moment of inertia at the end, I(t0) is the moment of inertia at the beginning, wt is the angular velocity at the end, w0 is the angular velocity at the beginning, △t is the beginning and end of the moment difference) 2012), that is, the moment of impulse received when the limb rotates is equal to the change of the moment of momentum when the limb rotates, which means that the effect of limb rotation is related to the moment of impulse generated when the muscle moment is acted on. When the moment of impulse is a constant, the moment of inertia of the limb is inversely proportional to the rotational speed. The smaller the moment of inertia, the greater the angular velocity. And since I=∑mttt2, the effective way to reduce the moment of inertia is to reduce the radius of rotation. This is consistent with the conclusion of Vladimir, an American expert in sports biomechanics, that "any joint motion should be generated at the position where the moment of inertia of the distal joint is minimum and the angular velocity of rotation is maximum" (Vladimir M. Zaziorski, 2000).

The principle of minimization of moment of inertia is widely used in Wushu. For example, the big leg should be folded as far as possible to reduce the moment of inertia and increase the rotational angular speed in the stage of knee lifting and hip rotation during Sanda flogging or side kicking. For spinning 720°, feet and legs are required to be together in the air; for whirling 720°, feet and hands are required to be together and the body is kept straight to complete the air rotation; for flying pendant 720°, feet and hands are required to be together and the body is required to stand upright to complete the rotation. Standing upright with feet and hands together significantly reduces the effective radius of rotation, reduces the moment of inertia, and thus increases the angular velocity of rotation, making the movement smoother and more aesthetically pleasing. Therefore, in Wushu practice, we should strictly follow the principle of minimizing moment of inertia, adjust the radius of rotation by changing the posture of the body, reduce the moment of inertia, so as to achieve the purpose of increasing the angular velocity of rotation.

3. Principle of impulse formation

This is another principle that is important to the power and speed of Wushu, and is related to the formula of impulse and momentum: I= integral t02 (∑F)dt= integral F0Fdp= p-P0 (where I represents the total impulse of the resultant force on the particle in t-t0 time, p and p0 respectively represent the initial and final momentum of the particle). The formula shows that a large momentum increment is necessary to generate a large impulse. To get a large momentum increment, either there is a large average force, or the force acts for a long time, or the change in initial and final velocity is the largest. If the initial and final momentum increment of the striking body is increased by rapid recovery at the moment when the striking action is completed in free combat, so as to produce a larger impulse of the struck body, this process can be considered as the subject of force, and the striking body is considered as the force object. When the body contacts the target in free combat, swing fist, side kick and other movements, the muscle contraction of each joint of the body is actively strengthened to form a second force to increase the average force and increase the momentum change of the hit body.

In the jumping difficult movements of Wushu routine, the quality of pushing off the ground directly affects the height of jumping and the completion of the movement. On the one hand, the body subconsciously can increase the pre-elongated length of muscles in the jumping stage, forming stretch reflex and increasing muscle strength, thus increasing the upward elasticity of the ground on the human body. On the other hand, it can prolong the action time, increase the impulse, and promote the momentum of the human body to change greatly, so that the human body can obtain the conditions of the air, and successfully complete the action.

4. Principle of energy saving

This is about the rational use of metabolic energy for specific tasks, also known as the "muscle excitation restriction principle." Some studies believe that the adaptive mechanism in the learning process of motor skills reflects this principle (Bartlett.RM, 1992). This principle is widely used in the Wushu movement technology, in the learning process of Wushu movement some redundant movement gradually reduced. This requires different movements in Wushu exercises to make muscles in specific parts contract to produce force.

For example, in the exercises of basic Wushu, such as forward kicking, inside closing, outside swinging and single patting, the waist should be controlled as far as possible to avoid large forward and backward movements, so that the hips can exert force to save energy consumed by unnecessary movements. The existence of large joint muscles in human body shows that the principle of energy saving plays an important role in exercise.

5. Principle of extending acceleration distance

By the principle of functional relationship between delta E = F delta r = F | delta r | cosine theta) (F represents the force, delta r represents the displacement, an Angle between the F and r theta, delta E for mechanical energy) in force, the formula shows that the larger mechanical energy (delta E) by increasing the average force (F) or increase range (s), and when F and | delta r | must be, When cosθ=1, △E is the maximum, and the mechanical energy (△E) is the maximum when both the force (F) and the motion displacement (△r) are in the same direction (Zhou, 1979). For example, in Sanda kicking and side kicking, the flexion and extension of the knee joint increase the effective distance, and the direction of the force and displacement should be consistent as far as possible. Research and practical experience have shown that the back-whip leg, back straight fist, back swing fist and back hook fist have greater power than the front whip leg, front straight fist and front hook fist. The reason is that the force of the latter is longer than that of the former, so that the increment of mechanical energy is larger than that of the former.

For example, in the wushu routine takeoff movement, first move in the opposite direction, and then take off vertically to the ground, in order to extend the distance of force action, reduce the Angle between force and displacement to increase the mechanical energy when taking off. However, it should be noted that when the knee joint flexion and extension reaches a certain extent, it must be stopped in time, otherwise the body will turn into a squat position, which will cause the muscle not to have complete elasticity, resulting in muscle relaxation (Li＆Ge, 2003).

Research Evident

1. Sports biomechanics research

1.1 Analysis of sports skills and tactics

Sports biomechanics is a discipline that applies the knowledge of biology and the principles and methods of physics and mechanics to study the movement laws of human body (or equipment) in sports. In the study of sports technology, one of its main purposes is to reveal the principles of movement technology, especially in the field of competitive sports. The principles and methods of sports biomechanics are the main means to analyze and diagnose the characteristics of athletes' skills and tactics, and also the main methods to improve sports performance, explore technical rules and improve movement skills and tactics.

With the development of science and technology, the high-end instruments and equipment are more advanced, and the sports biomechanics testing means are more diverse, which makes the sports technology has been greatly improved. In this conference, video analysis, high-speed photography, sensor measurement, infrared high-speed motion capture system, laser tester, three-dimensional force measuring table and so on are used to analyze sports techniques and tactics, mainly two-dimensional and three-dimensional video analysis of technical movements, at the same time combined with a variety of sports biomechanical testing means to analyze technical movements have also emerged. Zhou Haoxiang et al. used two methods of video point shooting analysis and real ship dynamics test system analysis to diagnose the technical movements of different individual combinations of excellent men's double scullers, so as to provide reference for optimal pairing. The women's air rifle was of great significance as the first event of the Olympic Games. The SCATT laser tester was used by Geng and his team to measure six indicators, including aiming performance and shaking speed one second before firing, of four elite women athletes in the world to determine the key factors affecting the athletes' shooting performance. In track and field, taekwondo, tennis, table tennis and other events, two-dimensional and three-dimensional video analysis methods are often used for quantitative analysis of technical movements to find the advantages and disadvantages of movement techniques, and provide a basis for improving sports training and performance (Zhao, 2022).

The holding of the Beijing 2022 Winter Olympic Games is of epoch-making historical significance to China, representing the improvement of China's comprehensive strength and national image. As a part of the comprehensive strength of the country, it is particularly important to increase the research on technical movements. Zhou Jihe et al. used virtual reality technology to conduct 3D reconstruction demonstration of the sliding movement technology of short track speed skating in Wudajing 500m out of curves; Du Chuanjia et al. used Signal-TEC 3D V1. OC video analysis system to analyze the two-pole push technique of 8 male cross-country skiers. Guo Tianlong et al. used the wireless inertial motion capture analysis system to collect and analyze the leg movements of three U-slot double-board skiers, providing efficient, visualization and data support for the training process.

1.2 Sports injury and sports rehabilitation

The occurrence, development and rehabilitation of sports injuries are all related to the stress on the injured site. Sports biomechanics provides test means and research methods for exploring the causes and mechanisms of sports injuries and evaluating the rehabilitation effects, and serves the fields of competitive sports, public health and special groups. The biomechanical diagnosis and analysis of sports injury and rehabilitation training mainly focus on the field of competitive sports. Xu Yongxin et al. established the injury model of international elite athletes on snow by analyzing four key parameters, including injury rate, severity, injury site and type, injury factors and causes, of elite athletes in major international level snow events. It is suggested that relevant scholars further explore the influence of internal and external factors on injury, and establish a comprehensive and localized injury detection system by injury and trauma model reconstruction. Ren Yuanyuan et al. simulated the visual tracking task of soccer players in real games with 3D-MOT task and found that sports fatigue under the visual tracking task increased the risk of non-contact ACL injury. With the increase of fatigue degree, the athletes' landing mode changed from "soft" to "hard", prone to joint instability. Biomechanical diagnosis and analysis of sports injury and rehabilitation training mainly focus on the field of competitive sports (Wang et al., 2016).

Public health has broadened the new field of sports biomechanics research, and the research content has expanded from the "technical diagnosis" of competitive sports to human health. Liu Dan used the method of literature to summarize the injury factors related to overweight people, and discussed the impact of jumping mode on the kinematics, dynamics and sports injuries of the lower limbs of overweight people. Qi Xuan used Zebris FMM-System planar pressure gait analysis System to test patients with a history of ankle joint injury, and discussed the characteristics and influencing factors of balance ability of patients with a history of ankle joint injury under four postures. With the proposal of the concept of sci-tech Winter Olympics and the rapid development of competitive sports for the disabled, sports for the disabled are developing in a comprehensive and diversified direction (Sun et al.,2020). At the same time, biomechanical research on sports injuries of the disabled is also on the rise. Zhou Titian et al. comprehensively studied how wheelchair athletes change the performance of wheelchairs under the influence of various conditions, so as to understand the injury mechanism of wheelchair athletes in a more comprehensive way. According to the investigation of 17 professional players of the

Chinese Disabled table tennis team, Yuan Lingwei learned: The injury sites were shoulder (92.86%), waist (85.71%) and neck (50%). The injury causes were fatigue injury (88%), other injury (12%) and acute injury (4%). After sports injury, massage, acupuncture combined with acupoint, cupping therapy was effective.

1.3 Application and development of sports equipment, training equipment and testing instruments

With the development of modern science and technology, competitive sports become more and more necessary for high-tech equipment, and the development and application of sports biomechanics in equipment and training equipment become more and more important. He Xiao used Isomed2000 dynamometer to test the muscle strength of the extensor and flexor muscles of bilateral knee joint of 24 excellent table tennis players (12 male and 12 female). The test found that the peak moment and relative peak moment of flexor and extensor muscles on both sides of the knee joint of Chinese table tennis players decreased with the increase of angular speed. Test the theory that the tension of muscles is inversely proportional to the rate of contraction. Xiong Jun et al. used Vicon system and DaeDo electronic protection to study the sensitivity rule of whirlwind kick of 12 professional taekwondo athletes, and found that the higher the competition level, the greater the score threshold, and the greater the impact force required. In the field of mass sports, sports biomechanics has become more and more targeted, scientific and practical in the development of equipment and instruments. Wu Hao from Beijing Institute of Sports Science developed autonomous stepping test equipment to improve the situation in aerobic endurance module of the elderly's physical fitness test, increasing the accuracy and safety of the elderly's physical fitness test data.

1.4 Sports Shoe Technology

Sports biomechanics is an important basis and premise for the development and progress of sports shoes technology. For the public, the main function of sports shoes is to protect the feet, while for athletes, the main function of sports shoes is to improve sports performance, reduce sports injuries and physical consumption (Zhang, 2015). Wang et al. used Vicon three-dimensional motion capture system (T40s) and Kistler three-dimensional force measuring table (9287B) to measure the kinematic and dynamic data of subjects wearing bare minimalist shoes and ordinary shoes while walking and fast walking. The data showed that the minimalist shoes could effectively reduce the lateral knee joint load during walking and fast walking. Marathon is a long-distance road running sport. For runners, the performance of running shoes plays an important role in finishing the race smoothly. Quan Wenjing et al improved the heel stability of running shoes by changing the hardness of inner and outer midsoles and heels, and adding three different hardness to the middle soles of running shoes. The experiment proved that designing the middle soles with different hardness in the inner and outer heels could improve the stability of runners' ankle joints. In the field of competitive sports marathon, Yang Chenhao et al. explored the interactive response of Achilles tendon biomechanics between the ethnic group, running speed and shoes by comparing the Achilles tendon loads of high-level marathon runners of Asian and African descent at different running speeds and shoe conditions.

1.5 Analysis of gait and neuromuscular control

Gait is a behavior characteristic of human walking, and normal walking does not require thinking. However, the control of walking is very complex, including central command, body balance and coordination control, including the coordinated movement of muscles and joints such as hip, knee, ankle, foot, shoulder and neck, so gait has also become a research hotspot (Qian et al.,2006). Zhang Xiaopei selected 36 stroke patients who could walk independently in the Bayi Rehabilitation Center of Sichuan Province and randomly divided them into experimental group and control group. The experimental group added the training of lower limb rehabilitation robot on the basis of conventional rehabilitation treatment. After 6 weeks, the experimental group improved the side stride length, stride length, stride speed and stride frequency and was better than the control group (P< 0.05). Wang Zeping from the School of Physical Education at Ningbo University and Liu Qinhua from Beijing Sport University jointly studied gait and shoe design. Niu Sen et al. used Belgium Footscan plantar pressure test system to test and analyze gait plantar pressure of 87 recruits in a unit of the Central Theater Command, providing theoretical basis for recruits to implement corrective training and injury prevention. Improving gait stability and balance ability of the elderly and effectively preventing falls has become one of the important problems in sports biomechanics research. Zhang Qinglai et al. adopted T Mobility leb gait and balance assessment system to conduct iTUG test on 60 elderly women, and the test objects were divided into Tai chi group, walking group and no exercise group. The results showed that tai chi can enhance the trunk posture control ability of elderly women, improve walking speed and gait stability, and effectively reduce the risk of falling in the elderly. He Feng et al. used Qualisys infrared far-light motion capture system to measure the gait of elderly people on the plateau, explore the comprehensive gait kinematic parameters of elderly people on the plateau, and screen out valuable gait indicators as sensitive indicators for evaluating fall risk.

Neuromuscular control refers to the ability of the dynamic stability system of the human body to be unconsciously stimulated during sports to prepare for instability in advance, or to respond in time according to corresponding movements and loads during sports to maintain joint stability (Zhang＆Zhang, 2017). Duan Yucheng et al. trained second-level athletes suffering from patellar pain syndrome through neuromuscular training and gluteal muscle and quadriceps muscle strength exercises. After 4 weeks of training, the landing Angle was significantly improved when pain occurred in squatting on one leg, and the distance of right front touch was significantly improved in Y balance test. Hu Xin et al. evaluated the running, jumping and hopping of 4-6 years old children through gross motor development test, and analyzed the integrated EMG and timing of muscles when completing movements by using BTS surface electromyography test system. The results showed that the IEMG value and muscle contribution rate of rectus femoris of 4-6 years old children were significantly greater than that of gastrectus and biceps femoris. The tibialis anterior muscle was significantly smaller than the gastrocnemius, rectus femoris and biceps femoris.

1.6 Teaching theories and methods of sports biomechanics

In accelerating the scientific process of sports training, sports biomechanics plays a vital role. At the same time, it is of great significance to innovate sports biomechanics teaching theory and diversify teaching methods. In this conference, the teaching theories and methods of sports biomechanics were also studied by many scholars. Zhen Jie et al, aiming at the phenomenon of low enthusiasm and lack of drive of students in learning physical education theory courses, boldly proposed the idea of constructing "golden course" of Sports Biomechanics in a task-driven and evaluation-driven way. By excavating the hidden ideological and political elements in the course of Sports biomechanics, Shi Yan integrated the cultivation of values into the course construction, took moral cultivation as the overall goal and curriculum teaching as the starting point, and discussed the path of integrating ideological and political elements in the course of Sports Biomechanics. With the rapid development of modern science and technology, the Ministry of Education attaches great importance to the role of virtual technology, artificial intelligence and other high-tech technologies in the development of disciplines and personnel training, and immediately issued a number of policies such as the 10-year Development Plan for

Education Informatization (2011-2020) and the Action Plan for Education Informatization 2.0. Hao Minghui et al. discussed the feasibility and teaching value of applying virtual reality technology to sports biomechanics teaching by analyzing the feasibility of applying virtual reality technology to sports biomechanics teaching.

2. Research on the Training of Competitive Wushu Routine

2.1 Research on the concept of competitive Wushu

"Wushu" used to be called "Hand Fighting", "Fighting" and "Martial arts" in ancient times. In modern times, it was called "national art". After the founding of New China, they were collectively referred to as "Wushu" (Chinese Wushu Dictionary Editorial Committee, 1990). Through research on the development history of Wushu, a lot of experts and scholars have differing opinions on Wushu. The difference is mainly due to different perspectives, and they focus on the description of broad sense and narrow sense, traditional and modern. At present, the relatively consistent discussion on the concept of Wushu is that Wushu is a traditional Chinese sports item with the main content of fighting, the form of routine, fighting and martial arts, and the emphasis on both internal and external training (Cai＆Zhou, 2009). The routine movement refers to a complete set of exercises based on the movement of attack and attack, the changing laws of the movement of attack and defense, the slow movement of movement, the rigid and soft movement, the virtual and the solid movement, etc. Taking "function" as the classification standard, wushu can be divided into competitive wushu, fitness wushu, school wushu and practical test wushu. Competitive Wushu refers to the high-level Wushu competition, which is a Wushu training and competition activity in order to maximize the individual athletic potential and strive for excellent results. It is characterized by specialization, professionalism, high level, overload and outstanding competitiveness. Competitive Wushu officially appeared after the 1950s, and has formed a complete system up to now (Qiu, 2004).

For the definition of "competitive wushu routine", different experts and scholars have given different explanations. However, in many definitions of "attributes of acrobatic movements", "forms of routine arrangement" and "competitive" as key words, the majority of scholars are relatively consistent views. Therefore, the definition of "competitive Wushu routine" is generally expressed as: a complete set of exercise forms of competitive sports events arranged with the movements with the meaning of attack and defense as the main material, with competitive competitions as the main features, and with the main goal of creating excellent athletic achievements and winning competitions. It is the product of the modernization development of Chinese Wushu. As the intersection of Wushu sets and competitive sports, it has obvious national traditional characteristics and modern competitive sports characteristics (Luan et al., 2005).

2.2 Research on children's training

Youth sports training is the beginning of athletes' career training, is to become the start of sports athletes, if not from the selection of young athletes, then the result is not only a waste of national talent training resources, but also lead to young people's own ability can not dig and play.

The science and rationality of youth wushu routine training plays a vital role in the follow-up training of youth. At present, the research on teenagers mainly focuses on the training of athletes from the physiological characteristics of athletes, and develops the physical quality of athletes according to the physiological characteristics (Zhao, 2013). Wang Zhihui pointed out that 7-9 years old is the best age for children to conduct initiation training in Wushu, and 12 years old is the best time for special training in Wushu. Seizing the critical period of youth training, athletes can get twice the result with half the effort in training effect (Wang＆Zhou, 2005). During this period, the general quality and special quality of athletes should be trained scientifically and reasonably, which should strengthen the movement specification, form the correct technical concept, improve the external performance of the movement, master the coordination of the movement and the key points of power, clarify the technical points of Wushu movements, and clarify the distribution of power points and the sequence of power. The requirements for children's Wushu technical training vary with different stages of development. It is necessary to follow the training principle of gradual progress, from the simple to the deep, from the simple to the complex, from the easy to the difficult, not against the order of physical and mental development of the person and training, should adhere to the principle of "comprehensive physical and mental training". We should not only grasp the training of physical quality, but also grasp the training of psychological quality. At the same time, we should also grasp the selection of materials, so as to make the training receive good results. But there are many shortcomings in the Wushu training of teenagers at present: Tang Mingwei points out that the basic training of young Wushu players is not solid enough, coaches and teenagers themselves do not pay enough attention to the basic training of Wushu routines. As a result, special quality training is insufficient, athletes' special sports ability is not strong, basic skills and basic techniques are not detailed, and training surface is narrow (Tang, 2003). Therefore, we should strengthen the basic function training of athletes according to the characteristics of teenagers themselves. We should start with the details of the movements, standardize the techniques, correct every movement shortcoming of the athletes, and strengthen the exercises on the basic movements. At the same time, we should also train the coaches with professional skills and knowledge, understand the physical and mental characteristics of the athletes, and train the athletes accordingly. Solid foundation of athletes, for athletes professional, professional training to lay a solid foundation.

2.3 Competitive wushu training method research

The training research of routine mainly includes training methods, principles and plans, as well as training of physical quality, technique and psychology. The methods and principles of Wushu training not only play a vital role in whether the athletes can improve the athletic ability, but also affect the athletic performance, through the study of the methods and principles of sports can make the athletes to higher, faster, stronger direction. Wushu training of athletes includes not only general quality training but also special quality training, not only strength training but also flexibility sensitive speed training, not only physical training but also psychological training, training content is varied. So the research method involves more aspects.

Wu Xia pointed out that the reason why wushu routine movements could not be improved was not only caused by the error of technical movements, but also the performance of comprehensive problems caused by factors such as physical quality and ability, mastery of key technical points and psychological barriers (Wu, 2010). Therefore, the training effect of athletes is not ideal may be caused by the lack of one hand, may also be caused by a variety of reasons. We must differentiate and solve specific problems in a specific way. To find out the problem from the root, and then start from the specific problems, solve the problem, ensure the athletes' training effect is good, and achieve excellent performance in the competition, and in the training methods and training principles and other issues should follow the specific problem analysis, the current training methods are diverse, looking for new training methods is a huge challenge for coaches and athletes. The key is to start with the details and the overall situation and improve the athletic ability of the athletes. Therefore, the research on training methods and principles has become a research hotspot.

Zhang Linyan proposed the use of motor imagery for routine training. Through the training of athletes' imagery, the training of motor imagery has a positive effect on the training of athletes. By comparing the results of the movements shown by motor imagery with those actually completed, the shortcomings of their own movements were analyzed (Zhang, 1990). Improve the training movement and performance, at the same time in the training to give full play to the imagination of the athletes, and integrate it into the movement, so that it can further improve the training level. Xiong Yabing pointed out that the arrangement of physical training is very important for wushu training of athletes. Therefore, the training density should be improved in training, and the number of consecutive single movement and joint movements should be increased to improve special abilities. Physical training should be combined in learning and practicing key basic technical movements. These key basic techniques are accomplished by arranging loads for multiple repetitions during training; The physical and psychological quality of athletes should be improved in the training of static movements, especially in the walking training of Wushu routine (Xiong, 2010). Xu Shanshan pointed out that with the change of the rules of modern competitive routines, the athletes' flexibility is put forward higher requirements, so the training of flexibility should be more scientific and reasonable. In the flexibility exercise, according to the rules of movement, the method of step by step, active and passive combination and coordination and unity with other qualities should be adopted. In addition, flexibility should be developed timely and appropriately according to the relationship between human structural factors, the viscosity of human muscles, the physiological characteristics of athletes of different ages and the physiological characteristics of male and female sports, etc. (Xu, 2009). Wu Yunlong pointed out in the training research of competitive Changquan routine that in general physical training, the strength training method consistent with the jumping Angle of Changquan jumping should be adopted. A complete set of success rate training method is used in the special physical training. The physical and biochemical indexes of intelligent training and mental training were used to detect the load of training quantity and the fatigue degree of athletes. In psychological training, coaches analyze and solve problems by starting from the causes of athletes' bad mental state (Wu, 2009). Tan Bingchun and Li Jiang point out that the underperformance of athletes is due to the overestimation of the expectations of the performance; Affected by the degree of preparation for the current competition, the scale and significance of the competition, the competition opponent, the organization of the competition, the composition of the audience and their behavior; A state of low or excessive excitement; It is suggested that athletes and coaches should establish reasonable and appropriate expectations in the normal training. Before the competition, the coaches and athletes comprehensively analyze the competition situation, recognize the strength of the opponents, adjust the athletes' mental state, and improve their self-confidence; Strengthen pre-competition adaptability training; Stimulate the right and appropriate game motivation (Tan＆Li, 2010).

2.4 Research in the training of competitive wushu training concept

The training concept is the foundation of the research on sports training of athletes and coaches, the cognition of coaches and athletes at the ideological level, and the internal motivation and attribution of all actions of people. The change of the training concept is the source of competitive Wushu training. Only by changing the training concept can the training of Wushu be developed. Jiang Xia believes that the concept of Wushu training has changed from comprehensive to special, theoretical and personalized. All methods and means in the training should pay attention to the development of athletes' intelligence, and should be closely focused on the training of special techniques. According to the individual characteristics of athletes, coaches should have a deep understanding of the techniques, styles and characteristics of different wushu routines. Due to the differences in the physical form, physical quality, training level, technical style and temperament type of wushu athletes, it is necessary to combine the individual differences of athletes, select the correct training methods and means that conform to the actual situation of athletes, and scientifically arrange the training process (Jiang, 2008). According to the technical characteristics and development trend of wushu routine items, the training method should be changed from comprehensive physical quality training to highlighting the special quality training, and the training method is closer to the actual combat and modern high-tech all-round three-dimensional penetration of competitive wushu routine.

At present, there are few researches on the concept of competitive Wushu training. The change of the concept is conducive to athletes and coaches to pay attention to Wushu training, make Wushu training more scientific and feasible, and make the training results more excellent. The advanced concept of Wushu training can point out the direction of Wushu training, and is also the inner urge to pay action. Scientific and effective training methods and principles can help athletes to achieve good performance. The exploration of Wushu methods and original rules plays an important role in improving athletes' sports performance, so we should strengthen the research and methods of Wushu methods.

2.5 Wushu training under the influence of the changes in the rules of the contest research

The changes of rules and systems require the movements of athletes in competitions. Wushu movements in competitions are the accumulation of athletes in peacetime training, so the changes of rules and systems affect the training of athletes. The implementation and innovation of the new rules show the development level and development requirements of contemporary wushu and put forward higher requirements for the training of wushu.

The implementation and innovation of the new rules indicate that the traditional Wushu training no longer meets the requirements of the development of Wushu. The new rules require athletes to integrate "high, difficult, new and beautiful" into the training of movement quality, drill level and difficulty. The application of high-quality movement technology, good drill level style, drill difference and stable difficulty technology is the winning rule of the competition. These plays a positive role in promoting the development of competitive wushu routine. Therefore, in peacetime Wushu training, we should pay attention to the combination of basic skills, basic techniques and difficult movements, and the success rate and completion quality of difficult movements become the focus of training. In the arrangement of skills to foster strengths and circumvent weaknesses, to be good at innovation. In the arrangement of difficult movements of children's group, according to the characteristics of athletes' weak special quality, reasonable selection of different levels of difficult movements, in order to improve the success rate and completion quality of difficult movements. The new rules' modification of score value and setting of difficulty have higher requirements on the overall quality of athletes, especially the poor flexibility quality of male athletes and the poor speed and strength quality of female athletes. The new rules can motivate athletes to constantly improve and perfect their athletic ability, making the training more targeted and scientific (Zhang, 2007) (Chen, 2011).

In terms of system, Liu Tongwei pointed out that running high-level sports teams is the best way to train athletes in the future, improving the professional quality of coaches, changing the function of the government's sports authorities, and establishing clubs at all levels are important components of competitive Wushu training system mode. The training system of competitive Wushu should be constructed from these aspects (Liu＆Wang, 2002).

2.6 Physiological and Biochemical theory knowledge in competitive wushu training research

The research and evaluation of physical training methods and effects from physiological and biochemical aspects can make the training of athletes more scientific. Zheng Mengjun pointed out that in the training of pyrophosphokinase system energy supply and glycolysis energy supply ability in the development of wushu routine sports, the control of interval time is the key to improve the training effect. Blood lactic acid is a good monitoring index for the intensity and effect of training load of Wushu routine (Zheng, 2009). Through the analysis, it is concluded that the training of single movement and multiple groups can improve the athletes' quality of completing the basic wushu routine movements and develop the athletes' original phosphate energy supply ability (jumping power). It is found that the interval time of 90 seconds between each group is the best effect. Half a set of multi-group exercises: 2 minutes intermittent exercise intensity, exercise intensity accumulation effect is good, can effectively improve athlete's specific anaerobic capacity. Multi-group exercise of the whole set of movements: 6-minute interval has a better stimulation effect on developing athletes' tolerance to high lactic acid environment. As Wushu routine athletes usually use the training method of developing glycolysis energy supply ability 400 meters interval run, 4 minutes interval for the development of Wushu routine special physical effect is better. The 3 - minute interval jump box exercise has a good effect on the development of jumping ability and pyrophosphate energy supply ability of athletes.

Zhang Xuanhui and Guo Yongdong found that intense training time accounted for 2.9-11.89% in class training by testing heart rate. From the point of view of the characteristics of Wushu training, the focus of the class is to improve the movement power, speed, intensity; To improve the specification and quality of the movement, the intensity is small (Zhang＆ Guo, 1992). According to the load intensity changes of different training forms, the exercise load of the training course can be effectively controlled by mastering the training density, and the dynamic change of the load can be controlled within the appropriate range. At the same time, the structure of the course can be arranged according to the load intensity changes of different training forms, and the combination of single potential exercises, group exercises, full set of exercises, etc. Form different load structure, obtain different training effect.

Lu Lanfeng uses the theories of sports anatomy, sports biomechanics, sports physiology, sports biochemistry and kinematics to guide Wushu training. He understands the basic features of human sports anatomy and the basic connotation of Wushu sports as well as the mechanics principles to implement Wushu routine training. He also uses physiological and biochemical indicators to develop reasonable amount of exercise and training methods. For example, the evaluation should be carried out by observation method and athletes' self-feeling, physiological function measurement method should be used to evaluate, and rational training methods should be developed based on the principle of material and energy metabolism. Two kinds of training methods can be adopted in combination with the characteristics of Wushu. One is maximum lactic acid capacity training, and interval training is used to improve the performance (Lu et al.,2003). Mainly use routine interval training, half set of exercises, 3-4 people a group of the whole set of exercises. Physical fitness training can be used 400m running, variable speed running, etc. The other type is lactic acid tolerance training, which can use a complete set of additional exercises and two sets of continuous training methods. Generally, the body training includes 800m running, fast stepping up and down stairs and other means.

Through testing and using physiological and biochemical indexes to study athletes' metabolic and motor ability to improve Wushu and Wushu training methods, the testing and evaluation methods and research methods of competitive Wushu training are enriched, as well as the professional and special theoretical knowledge of coaches and athletes, so as to provide more methods for improving and evaluating Wushu training effects.

2.7 Research on Wushu training by means of sports technology

Training managers, scientists and doctors are participants in training activities, so training management is also a part of training, which determines that training management is not only responsible for managing the team, but also requires the management team to bring advanced concepts, knowledge and technology into sports training. Auxiliary sports training to improve the athletic ability and performance of athletes, improve the level of competition training of the whole team.

The development of computer brings convenience to our life, but also brings benefits to sports, more and more modern sports using computer, Wushu routine training is no exception, coaches can use the development of computer-aided training plan, training experts to solve training problems online, computer simulation technology, computer-aided movement analysis, computer-aided training monitoring, In order to scientifically detect and track the training process of Wushu routine, to help athletes achieve better results (Zhu, 2004).

3. Relevant research on aerial rotation

3.1 Research on vertical and vertical movements of Wushu routine

Guo Zhiyu et al. used infrared high-speed motion capture system, three-dimensional force measuring table and surface electromyograph to test the whirlwind foot 720° movements of elite wushu routine athletes. The kinematic indexes are height, vertical velocity and time. The kinetic index is the mean value of ground reaction force. The strength and discharge time of the original surface electromyography of the right leg were used to observe the muscle force characteristics of the right leg during takeoff and landing. It is suggested that the braking technique in the run-up and the step off the ground technique are the key, and attention should be paid to the rotation speed training and the muscle strength training of the right calf in the airborne stage (Guo et al., 2009).

Lin Beisheng made a technical analysis of 720° movement of cyclone foot by observing the video of the competition, and believed that the main factors affecting the success of 720° movement of cyclone foot were as follows: Mastery of technique, air proprioception, psychological factors, air height, static strength and flexibility. And according to the characteristics of the different stages of the formation of motor skills, such as generalization, differentiation, consolidation and automation, a technical training optimization scheme is proposed, which combines intuitive method with language method, integrity method with decomposition method, imagination method with representation method, difficulty reduction method with difficulty enhancement method (Lin, 2008).

By observing the competition video, Xiong Yabing made a qualitative analysis of the difficult movements completed by wushu routine athletes and believed that the factors affecting the quality of rotation movements were: Rotation degree, judgment and instantaneous muscle force, etc., and proposed to improve athletes' ability to coordinate force among muscle groups, cultivate athletes' sense of rotational force and ability of spatial judgment in training practice, so as to establish the best technical movement mode (Xiong, 2007).

Zhu Dong etc. Using the infrared high speed motion capture system and 3 d measuring machines, complete whirlwind on wushu athletes foot 720 ° and the pendulum suspension lotus 720 ° was tested and analyzed, found that his legs jump of the pendulum suspension speed higher than right foot jump up a whirlwind foot, but a whirlwind feet is bigger than the right toe swinging speed pendulum suspension lotus, It is suggested that a higher altitude is needed to ensure the completion of the rotation degree in the air when flying at 720°, and the altitude does not necessarily affect the completion rate of 720°. The goal of accelerating the rotation speed in the air can be achieved by increasing the rotation speed during takeoff and reducing the moment of inertia in the air. Moreover, the jumping height is not the only way to increase the rotation degree, and it is suggested to design targeted rotation auxiliary exercises in training practice to achieve the goal of increasing the rotation Angle in the air (Zhu ＆ Guo, 2006).

Through three-dimensional video analysis, she studied the change characteristics of the center of gravity of 720° movement of the cyclone foot. She found that the center of gravity of the national athletes dropped more than that of the first level athletes in the run-up buffer stage, and the buffer time of the first level athletes was longer than that of the national level athletes. In the take-off stage, the take-off time of first-level athletes is longer than that of national athletes, and the take-off time has a significant negative correlation with the vertical velocity off the ground. It is believed that the center of gravity of the first-class athletes is too high, and the potential of push and stretch cannot be fully developed, which leads to the vertical speed and heave Angle of the take-off. Shortening the run-up buffer and jump time is beneficial for athletes to gain greater vertical speed, which mainly depends on the rapid explosive power of the jump extensor muscle group and the coordination of each link of the body. It is suggested to strengthen the special explosive power and flexibility training of lower limbs for first-level athletes, and pay attention to the coordination training combining push and swing (Gao Li, 2008).

High difficulty jumping plays an important role in wushu competitive routines. According to the rules of competition wushu routine, the total score of each event is 10 points, including 5 points for movement quality, 3 points for drill level and 2 points for movement difficulty. Among the 2 points of action difficulty, 1.4 points of action difficulty, 0.6 points of connection difficulty and additional points of innovation difficulty are included. Action difficulty includes balance, leg method, jumping and diving. And according to the grade: A action (each action score 0.2), B action (each action score 0.3), C action (each action score 0.4). In the events of Chang quan, Sword, Broadsword, Spear and Stick, there are 22 movements with difficulty, 13 movements of jumping, accounting for 59% of the total, 11 movements involving aerial rotation, accounting for 84.62% of the total of jumping, and vertical rotation, as 6 movements, accounting for 54.55% of aerial rotation. In Taiji and Taiji sword events, there are 11 movement difficulties, 7 jumping movements, accounting for 63.64% of the total, and 5 movements involving aerial rotation, accounting for 71.43% of the total jumping movements, all of which are vertical rotation movements. In the events of Nan quan, Nan style broadsword and Nan style stick, there are 15 movements in difficulty, 11 movements of jumping, accounting for 73.33% of the total, 10 movements of jumping, accounting for 90.9% of the total, and 7 movements of vertical rotation, accounting for 70% of the total. In the same project, as the vertical Angle of 360°-720° progresses, the difficulty level of A-C changes. Therefore, jumping in the air and twisting occupies a large proportion in the difficulty, and its vertical movements occupy a large proportion in the air and turning movements, and the high score movements are mainly like this, which can be said to be an indispensable part of the competitive Wushu routine. Therefore, the objective reality that competitive wushu routine competition wins by difficulty forces competitive wushu athletes to seek to master difficult movements. Recognizing the biomechanical characteristics of difficult movements is an important premise for athletes to master difficult movements in competitive wushu routines. It is urgent to sum up the biomechanical characteristics of athletes completing difficult movements in competitive Wushu routine to enrich and develop the training theory of competitive Wushu routine. It is the only way to improve the training efficiency and the performance of competitive wushu routine athletes. The jump of 324C (720°) +1D (horse step) is the most difficult "movement + connection" in Wushu competition, and its score is 0.65. The smooth completion of this movement not only reflects the athlete's superb level, but also helps the athlete to achieve good results in the competition.

In the competition rules of competitive Wushu routine, there are two difficult actions with the highest score, respectively: "323C" and "324C", and the score value of these two difficult actions is 0.4 points. In these two movements can follow the horse step action, the action code is: "323C+1D" and "324C+1D", the score is also 0.65 points. Although the two actions have the same score and the same difficulty level, the characteristics of the difficult actions are different. The "323C+1D" difficult action can obtain a higher jumping height through a high-speed run-up, and the air time is also extended with the height, and it is easier to complete the air rotation 720°. The "324C+1D" difficulty requires both feet to take off, and cannot use a high-speed run-up to obtain a high jump height, which is more difficult for the athlete to complete 720° in the air. Therefore, compared with these two difficult actions, the difficult action "324C+1D" is more difficult. In addition, some scholars in China have studied the biomechanical characteristics of the difficult movement "323C+1D" and achieved success. However, the difficult movement "324C+1D" has not been studied by scholars, so it is more meaningful to study the biomechanical characteristics of the difficult movement "324C+1D".

3.2 Research on air rotation in other sports

Through three-dimensional video analysis and surface electromyograph, Li Lin et al. analyzed the kinematics and electromyography characteristics of high-level male figure skaters at home and abroad after three weeks of beating on the outer spot ice, and selected the kinematic indexes as follows: center of gravity, height, horizontal moving distance, airborne time, horizontal speed, vertical speed, lifting Angle, average rotational angular velocity, etc. The electromyography indexes are: the timing of muscle force generation and the integrated electromyography value (Li et al., 2015).

Kong Qingying used integrated electromyography value and median electromyography frequency signal indicators to reflect the muscle strength, muscle endurance level and fatigue degree of athletes when they completed the biweekly pull-out exercise, and screened out the main muscles doing work in each movement stage (Kong, 2014).

Pang Zhong et al. conducted biomechanical analysis of somersaults in gymnastics, and divided somersaults into early somersaults and late somersaults according to the direction of the moment of momentum obtained by the human body. The early somersault is considered to be the moment of momentum of the vertical and horizontal axes obtained by the human body when it leaves the apparatus. Late somersawing means that only the angular velocity around the horizontal axis is obtained when the human body leaves the apparatus. After flying, the athlete changes the relative position of the arm and torso by swinging the arm, which changes the inertia tensor of the human body and achieves the motion effect of flying and turning (Pang ＆Hong, 1983).

By using two-dimensional video analysis, Qin Haibo made a kinematic analysis of the male elite athletes in the halfpipe snowboarding event who completed the 720° turn of the front edge of their feet. It is found that: (1) there is a deviation between the air rotation Angle and the actual rotation Angle, and the difference is more than half a week. (2) The increase of the moment of inertia achieved by the arm extension action during grooving makes the "protruding - flying" instant obtain faster angular velocity of the turning body; (3) Effective push off action is a way to improve the exit speed and achieve flight altitude increase. Suggestions: (1) Arrange simulated rotation training according to the actual rotation degree. (2) Strengthen the training of air rotation and body posture control. (3) Strengthening lower limb muscle strength training can improve the effectiveness of the push off action, improve flight altitude and landing stability (Qin, 2011).

By using infrared high-speed motion capture system and three-dimensional force measuring table, Ma Lingbo made a comparative analysis on the kinematics of four aerobics athletes with different levels who completed 540° Korsak jump and 360° Korsak jump and then 180°. The results show that the key factors affecting the technical level of athletes are the timing of take-off and extension, the strength of take-off and extension, the early turn of take-off, the control of body posture after take-off, the speed of rotation, the height of take-off and the stability of landing (Ma, 2009).

To sum up, with the improvement of people's living standards, sports biomechanics plays an increasingly important role in the field of national health. The application of sports biomechanics methods to research various fitness exercises can reveal the biomechanical characteristics of fitness actions and the biomechanical effects of human organs, guide the fitness population to choose scientific fitness methods, effectively improve health and avoid sports injuries. With the promulgation of the National Fitness Plan, the application of biomechanics theory to study the national health has become a hot issue in the field of sports research. Sports biomechanics researchers mainly focus on the health issues of the elderly, while other groups are less involved. Therefore, in the future research process, Chinese scholars should expand the research group and focus on the field of national fitness. We will promote scientific fitness exercises for all. The change of times makes the training of competitive wushu routine also get great development. The present science and technology make the advanced teaching media, advanced concept and scientific method also integrate into the training of competitive wushu routine. With the continuous exploration of people, the competition rules of competitive wushu routine are constantly improved and changed, and the training system is constantly improved and supplemented. Wushu training also follows the pace above, constantly adjusting the training content, methods and ideas. With the development of science and technology, the high-end instruments and equipment are more advanced, and the sports biomechanics testing means are more diverse, which makes the sports technology has been greatly improved. Therefore, by testing the difficult movement "324C+1D" completed by high-level wushu athletes, this study analyzes the biomechanical characteristics of the movement, which can help the progress of competitive wushu routine difficult movement training.

4 ."324C+1D" action stage division

According to the main technical links of "324C+1D", the complete action is divided into four action stages: run-up, take-off, take-off and landing. In this study, eight feature images were selected in the complete motion (see Figure 1).

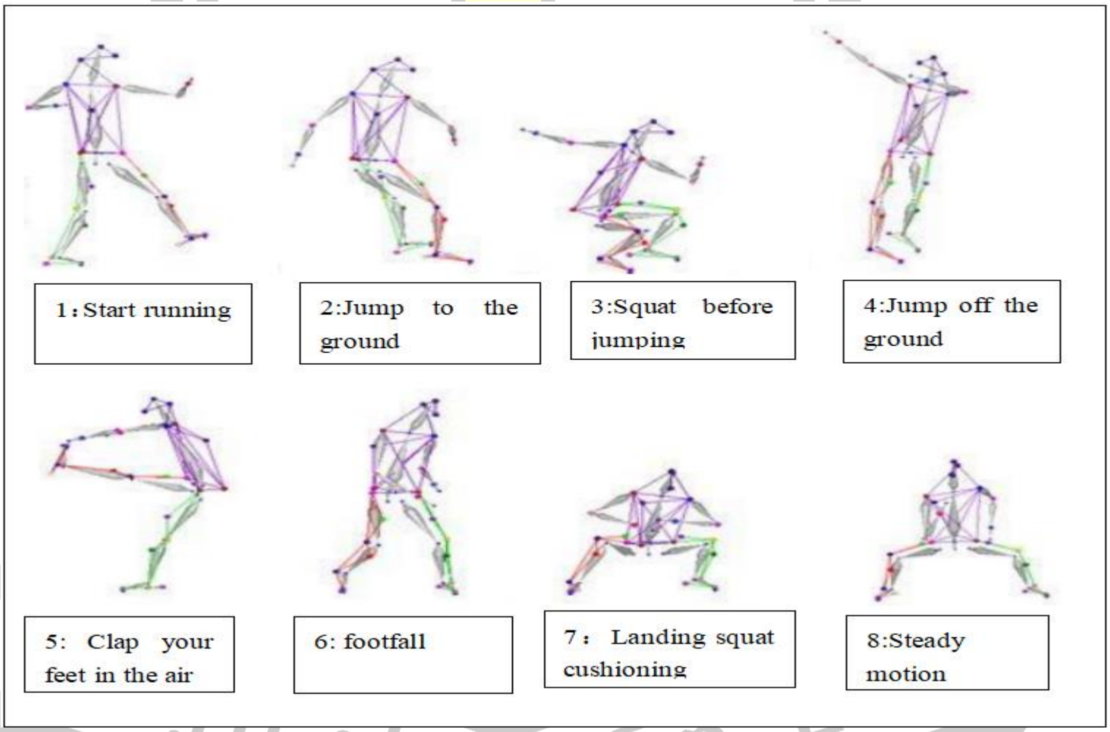

Figure 1 The main technical link diagram of the "324C+1D" action

4.1 Run-up stage

Run-up: The moment when the right foot touches the ground from the beginning of the run-up to the last step of the run-up.

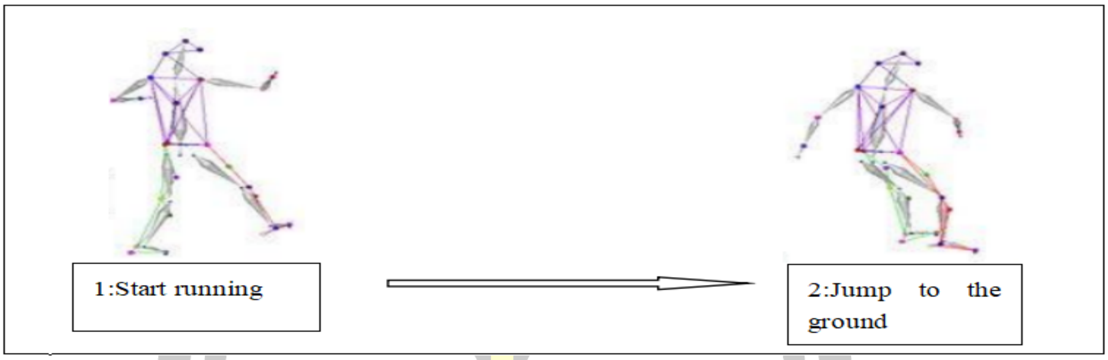

Figure 2 Run-up phase diagram of "324C+1D" movement

4.2 Take-off phase

Jumping stage: from the start of the run-up to the end of the jump to the ground moment.

According to the changing characteristics of the center of gravity of the human body, the jumping stage is subdivided into two sub-stages: squat and push. Squat stage: from the end of the run-up jumping feet to the lowest moment of the body's center of gravity; Push and stretch stage: from the lowest moment of the body's center of gravity to the moment of jumping off the ground.

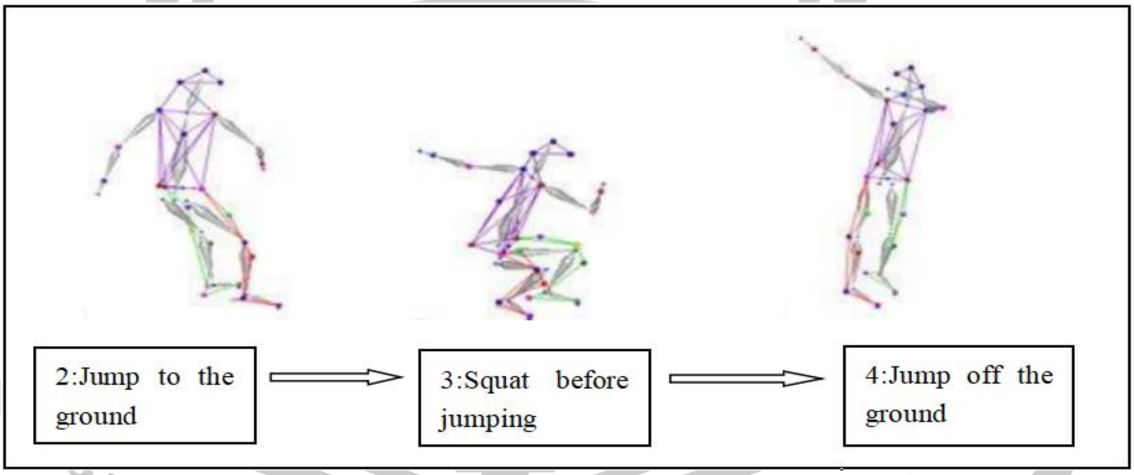

Figure 3 Take-off phase diagram of "324C+1D" action

4.3 Flight phase

Airborne stage: from the moment of starting the jump foot off the ground to the moment of supporting foot landing. According to the swinging leg characteristics of the swinging beat, the flying stage is subdivided into two sub-stages: off the ground to strike and strike to the ground. From the ground to the beating stage: from the moment of starting to jump off the ground to the moment of hitting the left and right feet; Tapping to the ground stage: from the left hand and right foot tapping time to the supporting foot landing time.

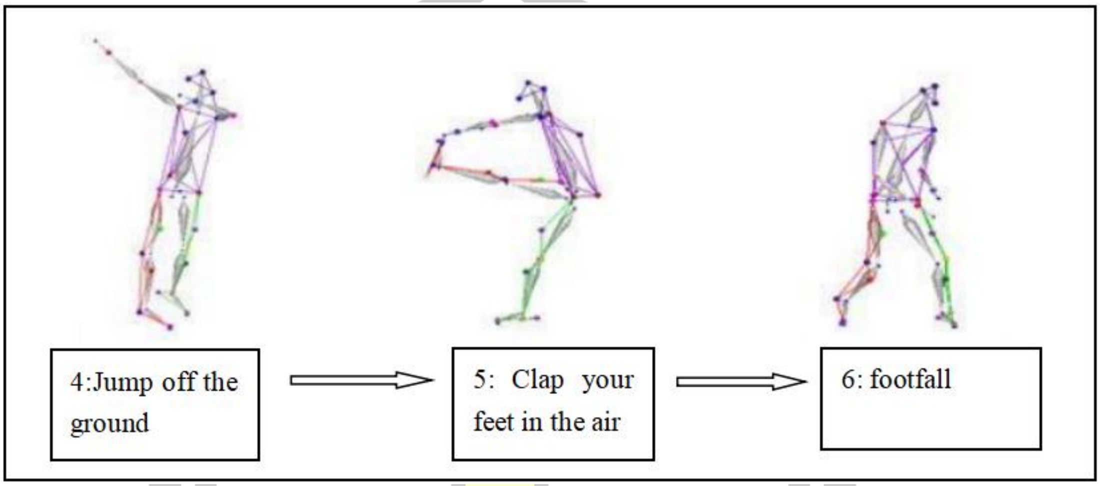

Figure 4 The aerial phase diagram of the "324C+1D" action

4.4 Landing phase

Landing stage: from the moment of the support foot landing to the stable movement of the horse step (the center of gravity of the horse step movement is almost no wave Move) moment. According to the changing characteristics of the body's center of gravity, the landing stage is subdivided into two sub-stages: landing cushion and action stability. Landing buffer stage: from the moment of the support foot landing to the moment of the lowest center of gravity of the human body; Action stability stage: from the lowest moment of the body's center of gravity to the stable moment of horse and foot action.

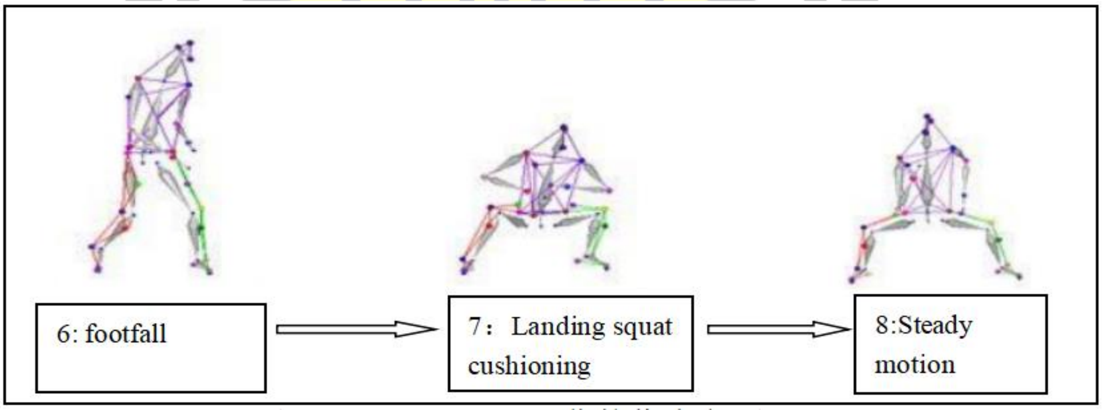

Figure 5 Landing stage diagram of "324C+1D" movement

CHAPTER III

RESEARCH DESIGN

This chapter describes the overall design of the study, including test objects, instrumentation, Data Collection Procedure, and statistical analysis. In this study, the test method will be used to obtain the biomechanical data of Wushu athletes of different sports levels completing the difficult movement "324C+1D", and the biomechanical characteristics of the movement will be obtained through analysis. The overall research framework is shown in Figure 6.

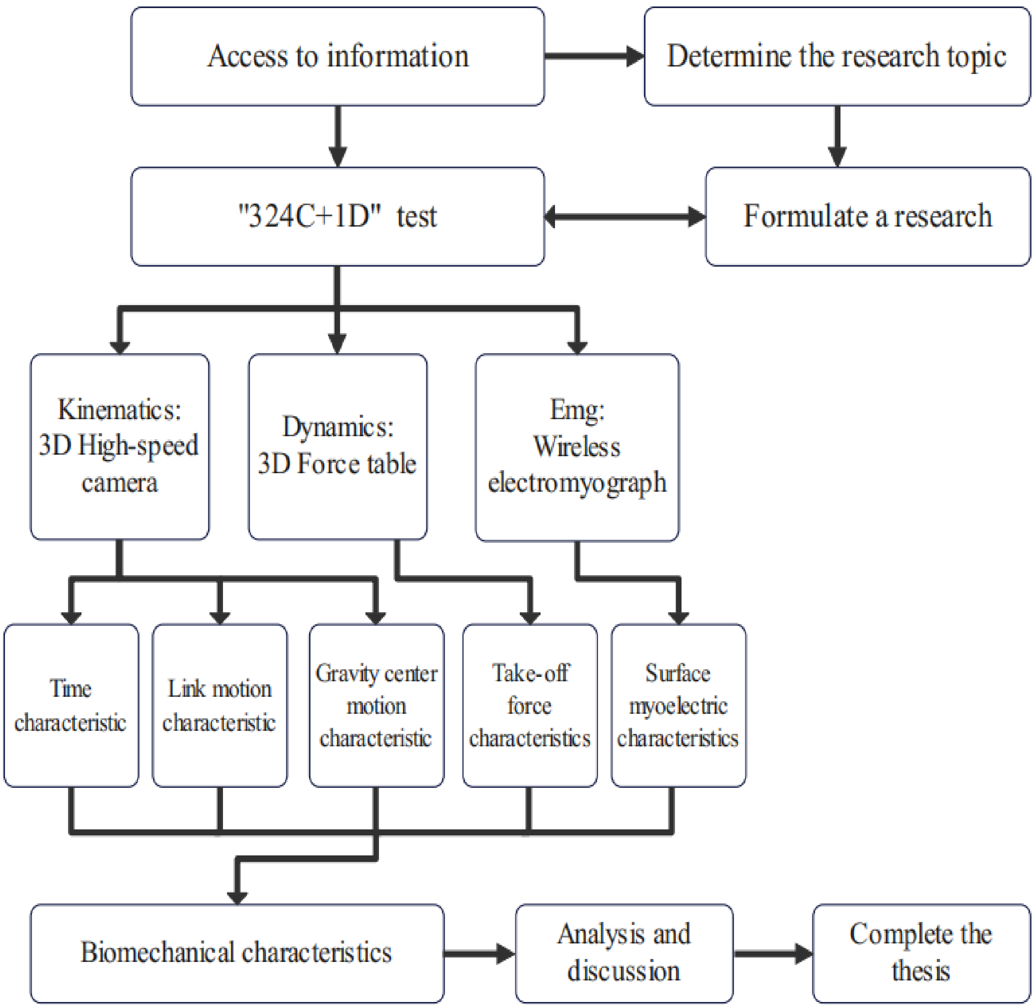

Figure 6 The Research Framework

Participants

There are 3 males national- level wushu athletes and 3 male first-level wushu athletes who can skillfully complete the "324C+1D" movement, a total of 6 athletes, aged 16-25, without obvious injuries in the past 3 months, voluntarily participate in this study test. The athletes who participated in the test are shown in Table 1. The athletes, all from Shaanxi provincial Wushu team, will have their rest time and diet strictly controlled to ensure the accuracy of the test content. These high-level wushu athletes of Shaanxi Wushu team have won the champion many times in the national wushu competition. Their athletic level represents the highest level of Chinese wushu. It is of high value to study the biomechanical characteristics of their difficult wushu movements. Before the test, the height, weight, training years and participation experience of the subjects were counted in detail, so as to facilitate the discussion of the significance of the difference in height, weight and age of athletes of different sports levels.

Table 1 Basic statistics of athletes participating in the test

No	Name	Age （y）	Height （cm）	Weight （kg）	Training years	Sports level
1	A	22	170	60	14	National
2	B	21	170	65	13	National
3	C	22	173	60	14	National
4	D	19	164	60	11	First level
5	E	21	175	82	10	First level
6	F	22	171	60	10	First level

The experimental testing was conducted by a professional testing team from the Experimental Center of Sports Biomechanics, Xi 'an Sports University, of which the author of this study was also a member. This professional testing team often participated in the research and testing of sports physiological and mechanical characteristics of several sports projects initiated by Shaanxi Provincial government, and obtained a lot of research results in sports biomechanics. During testing, the test team's responsibilities for each person are clear and fixed to ensure the accuracy of the test data.

Test Instrument

1. 3D High-speed camera system

Three Japanese SONY-RX10IV cameras, a set of SIMI Motion software of SIMI company, calibration frame using Agger 3D DTL framework calibration. 3D high-speed camera system can be used in the study of human movement, which can truly reproduce the movement and movement trajectory of athletes, and output the movement data of each link of athletes at any time, such as displacement, speed, angular speed, etc., so as to facilitate quantitative analysis. Combined with the principles of human physiology and physics, the research and improvement methods can make the observation of human movement get rid of the state of relying purely on experience. Enter the theoretical, digital era. 3D high-speed camera is a non-contact measurement, which has the advantages of not imposing extra load on the human body, not interfering with the body movement and measuring close to the actual condition. The detection and processing of human motion information takes human motion as the research object. Measure and analyze the displacement, velocity, acceleration and joint Angle of each part of the human body in the process of movement. 3 D high speed camera system is mainly used to study the kinematic characteristics of motion technology.

2. 3D force measuring table

One 3D force measuring table (Swiss KISTLER). Kistler 3D force bench test system is mainly used in the field of gait and balance analysis. It can accurately obtain the ground force, friction force, pressure and other parameters of different gait and posture. In this study, the ground force, friction force and pressure parameters of athletes' take-off action are mainly tested, and the ratio of push off force to body weight is calculated by combining with the athletes' body weight, so as to construct the mechanical characteristics of athletes' push off take-off stage.

3. The Wireless surface electromyography（EMG）system

American NORAXON surface myoelectric wireless telemetry system, with up to 4000HZ EMG acquisition frequency, USB power supply and connected to the PC end, transmission range of 30m, sampling frequency is optional 2000Hz or 4000Hz, sensor size 37*24.5*16.5mm length, width and height, weight 14g; Sensor base size 174*92*169mm length, width and height, weight 545g; Signal receiver size 261*36*29mm, weight 185g, with 16 channels.

The wireless surface electromyography test system can simultaneously collect 16-channel electromyography signal, real-time wireless data transmission, support the analysis of common indicators in the time domain and frequency domain of electromyography, such as mean value, maximum value, minimum value, root mean square amplitude (RMS), integrated electromyography (IEMG), power spectrum (PSD), and customized analysis. The wireless electromyography test system can obtain data such as the order of muscle work done and the amount of work done when athletes perform difficult movements without affecting their performance. Through data analysis, the surface EMG characteristics of athletes performing the technical movements can be obtained.

In addition to the professional equipment for sports biomechanics testing, we also need to use some common tools, such as laptops, during the testing process. Two computers, including Ariel 3D motion image analysis system, 3D force measuring table data analysis software, electromyography data analysis system, electromyography and force measuring table synchronization system, and an external synchronizer are installed.

Data Collection Procedure

This study has been carried out with the approval of Maha Salakan University under the Ethic code： 511-359/2023.

1. Composition and responsibilities of the test team

The test work and data process of this study was completed by a high-level professional test team, each member of which held a fixed test position and could not be replaced during the whole test process to ensure the stability of the test process and the accuracy of the test data. The composition of the test team and its testing responsibilities are presented in Table 2.

Table 2 Composition and responsibilities of the test team

Name	Employer	Major	Position	Test task
Yan	Xi 'an Sports University	Sports Biomechanics	Professor	High speed camera
Guo	AnKang University	National traditional sports science	Associate professor	High speed camera
Ma	Xi 'an Sports University	Sports Biomechanics	Lecturer	Force table

Wu	ChengDu Normal University	Sports training science	Professor	Force table
Zhou	Xi 'an Sports University	Sports Biomechanics	Professor	EMG test
Liu	AnKang University	Sports human science	Lecturer	EMG test
Ding	Xi 'an Sports University	Sports Biomechanics	Student	Test order arrangement

2. Test Time and test location

Test site: Sports biomechanics Laboratory, Xi 'an Sports University.

The test time: Test preparation (November 25, 2023), Formal test (December 6, 2023).

3. Test Method

3.1 Kinematic test

The researchers used a high-speed camera to collect kinematic data of "324C+1D", a difficult Wushu movement completed by volunteers, with a sampling frequency of 100 frames/s. All volunteers were asked to successfully complete three "324C+1D" movements. Each move completed by a volunteer is judged to be successful by three Level I Wushu referees on site, and the failure of the move will be required to complete a new move until the data of three successful moves is collected. In the follow-up study, the one with complete exercise data collection and the highest exercise quality will be selected for data analysis.

3.2 Dynamic test

The ground reaction force received by the subjects (Wushu athletes of national-level and first-level) when they completed the take-off of the "324C+1D" was collected by the 3D force measuring platform, and the sampling frequency was 500Hz. In the "324C+1D" test, the subject is required to complete the take-off with both feet on the loading platform during the take-off stage (i.e. the subject must complete the take-off on the loading platform without landing on the loading platform).

3.3 Surface electromyography test

The surface electromyography data of subjects (Wushu athletes of national-level and first-level) who completed the "324C+1D" were collected by the wireless electromyography test system, and the electromyography analysis was conducted. According to the movement characteristics of the "324C+1D" , different test muscles were selected in different movement stages, which were respectively the jumping stage (medial head of gastrocnemius muscle of left leg, medial head of gastrocnemius muscle of right leg, rectus femoris muscle of left leg, rectus femoris muscle of right leg, left external oblique muscle of abdomen, left erectus muscle of right erectus muscle). In the air stage (right thigh rectus femoris, right thigh gluteus maximus, right thigh biceps femoris, left abdominal external oblique, left spine, right erector spine); Landing stage (medial head of intestinal muscle of left leg, medial head of fat intestinal muscle of right leg, rectus femoris of left leg, rectus femoris of right leg, and left external oblique abdominal muscle).

4. Instrument installation methods

4.1 High-speed camera system

In this experiment, three Japanese SONY-RX10IV cameras were used for three-dimensional synchronous fixed-point shooting. The Angle between two cameras was 90 degrees, the camera height was 0.75 m, and the camera frequency was 100Hz. The calibration frame was calibrated by Agger 3D DTL frame.

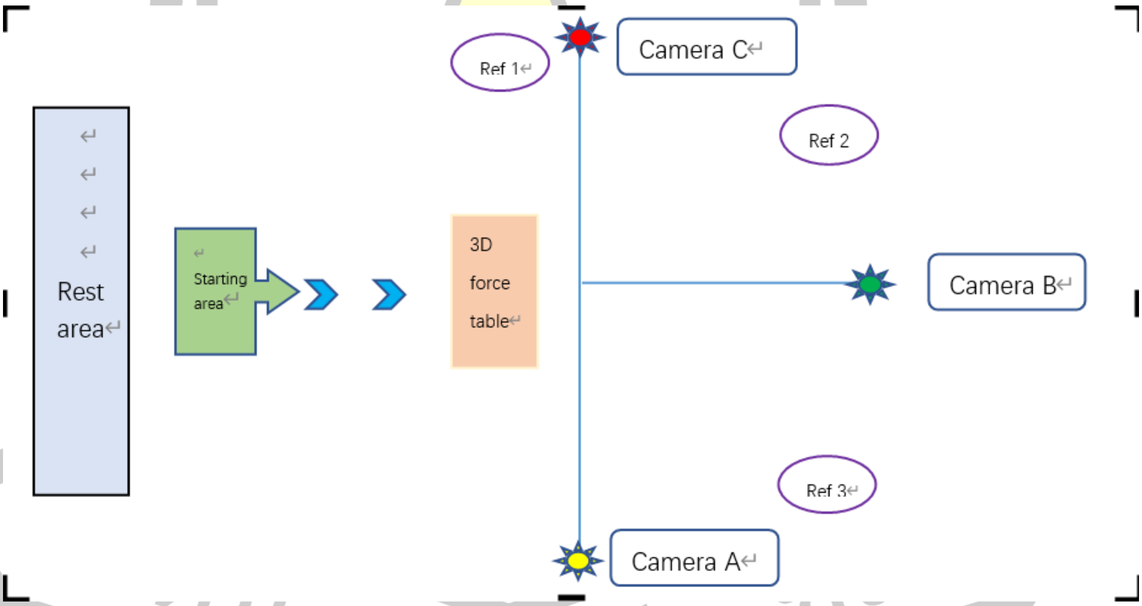

Figure 7 Test site layout diagram

4.2 3D force table measuring

A Swiss KISTLER three-dimensional force measuring platform was installed in the installation slot of the force measuring platform in the test site to ensure the accuracy of the test data of the force measuring platform. The whole test area was formed into a horizontal plane, which did not affect the movement performance of the subjects when they completed the "324C+1D" (see Figure 8). The X-axis direction of the measuring table was set to be perpendicular to the running direction of the subject.

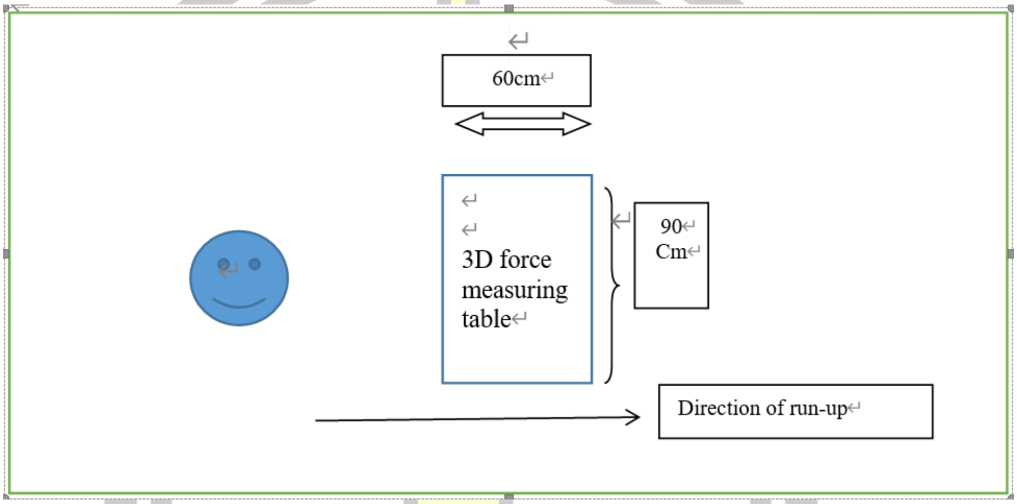

Figure 8 Installation diagram of 3D force table

4.3 Wireless telemetry myoelectric system

4.3.1 Selection of muscles

According to the movement characteristics of the limbs of "324C+1D" movement, different test muscles were selected in different movement stages, which were respectively the jumping stage (medial head of gastrocnemius muscle of left leg, medial head of gastrocnemius muscle of right leg, rectus femoris muscle of left leg, rectus femoris muscle of right leg, left external oblique muscle of abdomen, left erector spine muscle of right erector spine muscle). In the air stage (right thigh rectus femoris, right thigh gluteus maximus, right thigh biceps femoris, left abdominal external oblique, left spine, right erector spine); Landing stage (medial head of intestinal muscle of left leg, medial head of fat intestinal muscle of right leg, rectus femoris of left leg, rectus femoris of right leg, and left external oblique abdominal muscle). The starting and ending points and main functions of all 6 muscles (Table 3).

Table 3 The starting and ending points and main functions of muscles

Muscle Name	The Start and end Point of the muscle	The main function of the muscle
Erector spine muscle	From the back of the iliac bone, the back of the iliac section, the spine process of the lumbar spine, and the thoracolumbar fascia; The spinous process and transverse process, the mastoid process and the costal Angle of the ribs ending in the spine and thoracic vertebrae.	Lower fixation, both sides of the contraction, so that the head and spine extension; One side constricts, causing lateral flexion of the spine. When fixed, both sides shrink at the same time, so that the spine extends and drives the lower limb backswing; One side constricts, causing lateral flexion of the spine.
The external oblique	From the lateral surface of ribs 5-12; Posterior fascicle downward, end at iliac wax; The anterior muscle tract is transferred to the gentium, and participates in the formation of the anterior layer of rectus sheath, which stops at the linea alba. The lower margin terminates at the superior iliac spine and pubic tuberosity, forming the inguinal ligament.	In the lower fixation, one side contraction makes the spine bend to the same side and rotate to the opposite side; Both sides of the contraction, so that the spine forward flexion; When fixed, one side contraction makes the pelvis rotate and tilt to the same side, and the spine rotate and bend to the same side: both sides contract at the same time, making the pelvis tilt backward.
Gluteus maximus	From the outer back of the iliac wing and the dorsal side of the skeleton; The gluteal tuberosity of the femur and the iliotibial fasciculus end obliquely and below.	When near fixation, the thigh is extended and supinated at the medullary joint, the upper part of the thigh abduct, the lower part of the thigh adduct; In distal fixation, one side contraction causes the pelvis to rotate contralateral, and both sides simultaneous contraction causes the pelvis to tilt backward.
Biceps femoris	The long head originated from the ischial tubercle, and the severed head originated from the lower lip of the lateral linea aspera of the femur. The two ends coalesce at the fibula head with a long bond.	In the near fixation, the thigh is extended at the medullary joint and the calf is bent and supinated at the knee joint. In distal fixation, both sides contract simultaneously to make the pelvis backward, and one side contracts to bend the thigh at the knee joint.
Rectus femoris	Rising from the lower anterior iliac spine; Stop at tibial tuberosity.	When near fixation, bend the thigh at the joint of the skeleton; For distal fixation, extend the thigh at the knee joint.
Gastrocnemius muscle	The inner and outer heads of the intestinal muscles are located behind the inner and lateral parts of the femur respectively. Stop at heel tubercle.	When near fixed, the foot is bent at the stomp joint and the calf is bent at the knee joint; When distal fixation, bend the calf at the stomp joint and assist in knee extension.

Note: The left and right muscles have the same starting and ending points and functions.

4.3.2 EMG test electrode placement

Before the test, the electrode placement of the muscle to be measured was determined according to the anatomical marks on the body surface and by hand inspection. Shave the hair on the skin surface of the preset electrode and wipe with 75% alcohol. The two recording electrodes were attached to the highest point of the muscle abdominal bulge during the contraction of each muscle to be measured and in the same direction as the muscle fibers. The center distance of the two electrodes was 2cm, and then the elastic bandage was wrapped and fixed.

5. Instrument synchronization method

The synchronization between the electromyography and the force measuring table is connected with the synchronization software in the way of internal synchronization. The synchronization between the high-speed photography and the electromyography and the force measuring table is achieved by the way of external synchronization.

6. Instrument sampling frequency

6.1 High-speed cameras

The two high-speed cameras were installed horizontally in the test area at a 90° Angle, and the sampling rate of the two high-speed cameras was 100 frames /s.

6.2 3D force measuring table

The sampling frequency of the three-dimensional force measuring table was set as 500Hz.

6.3 Wireless telemetry for electromyography

Set the wireless telemetry EMG sampling frequency to 2000Hz and filtering frequency to 20-500Hz.

7. Test Preparations

7.1 Methods for collecting and recording the movement technical data of the subject

Subjects must be fully warmed up before the test. After the warm-up, all subjects will complete the "324C+1D” for 3 times. Three first-level judges will be invited to evaluate the completion of the movements.

7.2 Information Collected in Test preparation phase

General information: subject's height, weight, gender, training years, sports grade, competition experience, injuries, etc.

Environmental and instrument installation reference data: investigation of factors affecting environmental safety on athletes' complete movements, measurement of run-up, take-off point and landing site, etc., laying the foundation for the smooth conduct of formal test. For example: the tightness of the EMG electrode fixed, the impact of the site safety measures on the athletes to complete the movement, the force table installed in a special experimental tank does not affect the test accuracy of the force table, reduce the impact of site conditions on the accuracy of the test instrument.

8. Formal Test

8.1 Preparing for Tests

According to the problems found in the Test preparation phase, eliminate all the hidden dangers that may affect the accuracy of the test, install and debug the equipment and make preparation for the test. All subjects were asked to bare the upper half of their bodies, wear high-stretch tight shorts, and wear their usual training sneakers. All subjects were numbered and recorded before the test began. Warm-up activities were performed before the test began, and EMG electrodes were applied after full warm-up.

Electrode paste personnel, test athletes to maintain neutral, along the longitudinal axis of the muscle in the muscle belly of the most prominent position with double-sided adhesive tape, fixed with elastic bandage, then put on tights, to prevent the electrode slip or fall off during movement. Take the right leg of the lower limb as an example (the vastus lateralis, rectus femoris, vastus medialis, tibialis anterior, gastrocnemius, gluteus maximus, in order). Open the electrodes attached to the test athlete. Verify that the computer can connect to the electrode and perform signal detection.

8.2 Test Process

The athletes completed three times of "324C+1D" movement in the sequence of numbering. Three first-level judges were invited to evaluate the completion of movements at the test site, and the one with complete kinematic data collection and the highest movement quality was selected for data preservation. After the first subject finishes the test and saves the test data, the second subject starts the test and completes the test of all subjects in turn and keeps the test data properly. The test ends. Arrange and return the test instrument as soon as possible after the test.

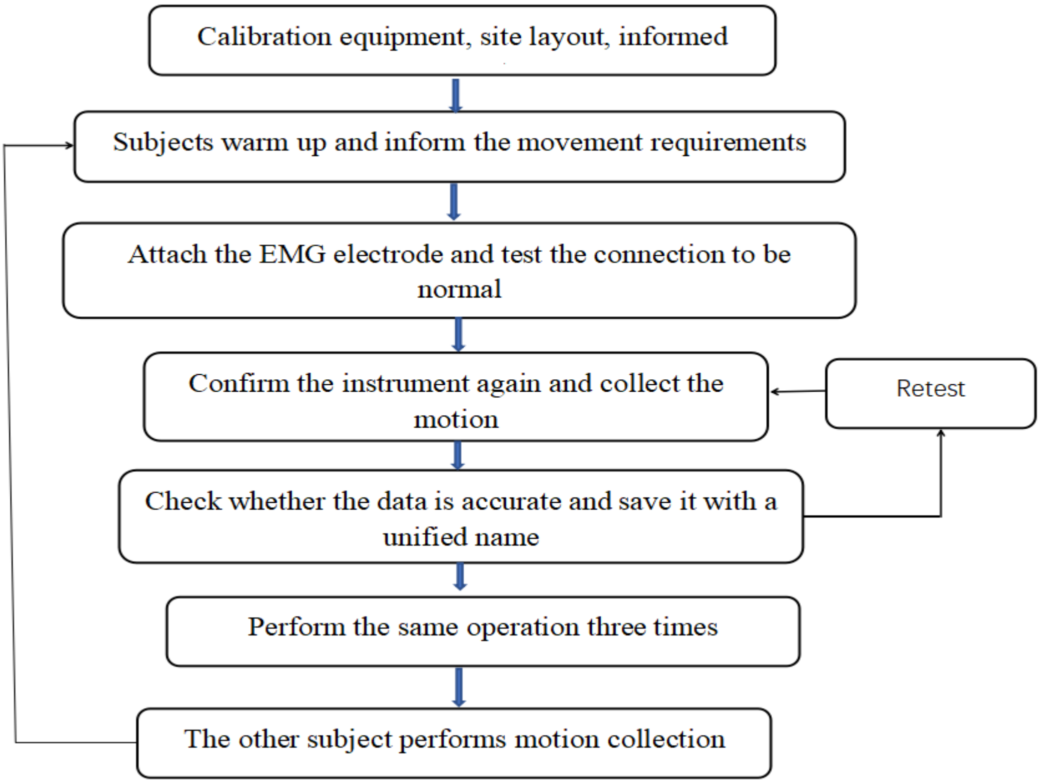

Figure 9 Test flow chart

8.3 Precautions

Ensure that subjects are fully aware of the test requirements and procedures, and ensure that athletes are fully warmed up before the test to avoid sports injuries. Test equipment hire professional operators to operate, to ensure the safety of the instrument. After the test, test data everywhere and back it up to ensure the safety of the test data.

Data Analysis

1. Data analysis of 3D high-speed camera system

1.1 Data method of 3D high-speed camera image

After the video shooting was completed, SIMI three-dimensional motion image analysis system and Hideji Matsui human body model were used to calculate the data, and the second order filtering method was used to smooth the data, and the interception frequency was 6Hz. Excel software was used to calculate and make statistics on the data indicators obtained.

1.2 Data selection and analysis of 3D high-speed camera system

1.2.1 Complete the time feature analysis of "324C+1D" movement

(1) Time analysis of run-up and take-off stage

The overall time of run-up and take-off stage, take-off squat and take-off push stretch were selected for characteristic analysis.

(2) Time analysis of the vacating stage

The time data of two sub-stages from leaving the ground to patting foot and from patting foot to landing were selected for feature analysis.

1.2.2 Complete the feature analysis of the limb movement links of "324C+1D" movement

(1) Analysis of the characteristics of body movement links in run-up and take-off stages

This part of data analysis mainly includes: swing arm speed peak, shoulder and hip torsion Angle peak, ankle, knee, hip Angle and other characteristic analysis during take-off and push extension stage.

(2) Analysis of the characteristics of limb movement in the airborne stage

This part of data analysis mainly includes: right leg swing speed, shoulder axis rotation angular speed and another characteristics analysis.

(3) Time analysis of the landing stage analysis of the characteristics of limb movement links

This part of data analysis mainly includes: shoulder and foot torsion Angle, knee fan Angle and another characteristics analysis.

1.2.3 Complete the analysis of the center of gravity movement characteristics of the "324C+1D" movement

(1) Analysis of the movement characteristics of the body's center of gravity during run-up and take-off

This part of data analysis mainly includes: the movement speed of the body's center of gravity in the run-up direction, the peak vertical speed of the center of gravity, the vertical movement distance of the center of gravity, the lifting Angle of the center of gravity at the moment of liftoff.

(2) Analysis of the movement characteristics of the body's center of gravity in the airborne stage

This part of data analysis mainly includes: vertical velocity of the center of gravity, vertical height of the center of gravity at the time of liftoff and landing, vertical movement distance of the center of gravity and another characteristics analysis.

(3) Analysis of the movement characteristics of the body's center of gravity in the landing stage

This part of data analysis mainly includes: vertical velocity of the center of gravity at the landing moment, vertical movement distance of the center of gravity at the landing buffer stage, and other characteristics analysis.

2. Data analysis of three-dimensional force measuring table

2.1 Data method of 3D force measuring table

Combined with kinematic data, the ground reaction (N) in different directions [left and right (X axis), front and back (Y axis), up and down (Z axis)] was found, including: the force value at the beginning of the action; Maximum force value and end time force value and other indicators.

2.2 Selection and analysis of 3D force measuring table data

The ground vertical reaction force peak value collected by the loading platform during the takeoff stage was selected for characteristic analysis.

3. Data analysis of wireless EMG system

3.1 Wireless EMG dativization method

The surface electromyography test indexes selected in this study were integrated electromyography and muscle activation timing. The electromyograph of the selected muscle of the subject was collected by wireless telemetry surface electromyograph during the completion of the movement. The sampling frequency was 2000Hz, and the filtering frequency was 20-500Hz. At the end of the test, the raw data was imported into the Noraxon analysis software to obtain the raw integral electromyography and muscle activity duration of each tested action muscle. The duration of muscle activation is based on the characteristics of the discharge of action muscles in this study. The integrated electromyography that is greater than 20% of the maximum value of electromyography and lasts for more than 0.05s is taken as the muscle activation area, and the duration of muscle activation is further converted into the percentage of the total time of the action stage.

3.2 Data selection and analysis of wireless EMG system

(1) Analysis of EMG characteristics of each athlete in run-up and take-off stage

The activation time and EMG integral value of relevant muscle groups collected by wireless EMG system in run-up and take-off stage were analyzed.

(2) Analysis of EMG characteristics of each athlete in the airborne stage

The activation time and EMG integral value of relevant muscle groups collected by wireless EMG system in the airborne stage were analyzed.

(3) Analysis of EMG characteristics of each athlete in landing stage

The activation sequence, activation time and EMG integration value of relevant muscle groups collected by wireless EMG system at landing stage were analyzed.

4. Complete comprehensive analysis of technical characteristics of "324C+1D" movement

4.1 Comprehensive analysis of technical characteristics in run-up and take-off stages

The action process of this stage is mainly analyzed. The description of the action process includes the analysis of the action coordination process of each link of the body, the process of pushing and stretching force, the activation time of each relevant muscle group and the overall characteristic analysis of the electromyography integral value. According to the results of comprehensive analysis, the influence of running on the completion of "324C+1D" movement is discussed respectively. The impact of take-off on the completion of "324C+1D" movement; The effect of torso rotation, arm swing and leg swing on the completion of the "324C+1D" motion before jumping.

4.2 Comprehensive analysis of technical characteristics in the take-off stage

The action process of this stage is mainly analyzed, and the analysis of the action coordination process of each link of the body, the activation time of each relevant muscle group and the overall characteristic analysis of the electromyography integral value are added to the description of the action process. According to the results of comprehensive analysis, the influence of air attitude changes on the completion of "324C+1D" movement is discussed.

4.3 Comprehensive analysis of technical characteristics in landing stage

The action process of this stage is mainly analyzed, and the analysis of the action coordination process of each link of the body, the activation time of each relevant muscle group and the overall characteristic analysis of the electromyography integral value are added to the description of the action process. According to the results of comprehensive analysis, the influence of landing connection on the completion of "324C+1D" movement is discussed.

5. Data Statistics and calculation

According to the research needs, statistical software Excel 2021 was used to establish a database of kinematic data, jumping force value data and EMG data obtained from the test. The test data in this study are divided into two groups, one is the data of national athletes completing difficult actions "324C+1D", and the other is the data of first-level athletes completing difficult actions "324C+1D". The data values of the same group of athletes in each stage of completing the difficult action "324C+1D" were analyzed by means and variance. The T test was carried out when comparing the data of the two groups of athletes in each stage of the difficult movement "324C+1D", and the difference of the data of the two groups of athletes was judged by the P-value. When analyzing the surface EMG data of each group of athletes, it was found that the surface EMG characteristics of each person who completed the "324C+1D" exercise were more effective through the analysis of individual values.

CHAPTER IV

RESULTS

This chapter analyzes the kinematic data, jumping force value and EMG data of "324C+1D", a difficult movement completed by national wushu athletes and first-level wushu athletes. This chapter is divided into the following four parts: The first part describes the process and stages of competitive martial arts routine "324C+1D"; The second part analyzes the biomechanical characteristics of the difficult movement "324C+1D" completed by the national wushu athletes according to the run-up and take-off stage, airborne stage, landing stage and other action stages. The third part analyzes the biomechanical characteristics of the difficult movement "324C+1D" completed by the first-level martial arts athletes according to the run-up and take-off stage, airborne stage, landing stage and other action stages. The fourth part makes a comparative analysis of the biomechanical characteristics of "324C+1D", which is a difficult movement completed by the national wushu athletes and the first-level wushu athletes, according to the run-up, take-off stage, airborne stage, landing stage and other action stages.

The units of kinematic index, mechanical index and myoelectric index involved in the data analysis process in this chapter are described as follows: The unit of action time at each stage is "second", abbreviated as "s"; The unit of Angle of hip joint Angle, knee joint Angle, ankle joint Angle, center of gravity lifting Angle, shoulder and hip torsion Angle, shoulder and foot torsion Angle, joint fan Angle, etc., is "degree", abbreviated as "°"; The unit of speed such as swing arm speed and swing leg speed is "meter /second", abbreviated as "m/s"; The unit of angular speed of shoulder shaft rotation is "degree/second", abbreviated as "°/s"; The horizontal movement distance of the center of gravity and the vertical movement distance of the center of gravity are equal distance units of "meters", abbreviated as "m"; The unit of weight is “kilogram”, abbreviated as "KG"; The ground reaction force value is “Newton”, abbreviated as "N". In this study, the ratio of the ground reaction force value to the athlete's own Body Weight is used as the index, and the unit is “Body Weight”, abbreviated as "BW". The unit of integrated myoelectricity is “micro volt square meter”, abbreviated as "µVs".

1. The technical characteristics analysis of difficult movements "324C+1D" completed by national athletes

1.1 Analysis of technical characteristics of run-up and take-off stages

The take-off requirement of the difficult action "324C+1D" is to take off with both feet and complete the run-up within 4 steps, so the run-up speed requirement of this action is not high, and the time characteristics of the run-up stage, the characteristics of the center of gravity movement speed, the swing arm speed and other characteristics have a very small impact on the completion of the movement, which can be ignored. Therefore, the time characteristics, center of gravity movement characteristics and swing arm speed characteristics of the run-up stage were not analyzed in this study.

1.1.1 Time characteristics

Table 4 Time for take-off stage (s)

Athlete \ Action stage	Jump squat	Jump and push	Take off
A	0. 20	0. 18	0. 38
B	0. 20	0. 22	0. 42
C	0. 17	0. 23	0. 40
$\overline{x} \pm s$	0. 19±0. 02	0. 21±0. 03	0. 40±0. 02

1.1.1.1 Total Time Analysis of the take-off phase

From the total time of the take-off stage (see Table 4), the average time of the national athletes to complete the take-off stage of the "324C+1D" movement is 0.40s, and the standard deviation is 0.02s. The total time of the three athletes participating in the test was very close to that of the three athletes. Athlete A took 0.38s to complete the take-off stage of the "324C+1D" movement, which was the shortest time among the three athletes. Athlete B took 0.42s to complete the take-off stage of the "324C+1D" movement, which was the longest time among the three athletes.

1.1.1.2 Time analysis of take-off squat stage;

Judging from the time of the sub movement stage of take-off squat (see Table 4), the average time of the national athletes in the sub movement stage of take-off squat when completing the "324C+1D" movement is 0.19s, and the standard deviation is 0.02s. Athletes A and B took the same time to complete the sub-movement stage of

"324C+1D" movement jumping and squatting, both of which were 0.20s; Athlete C took 0.17s to complete the sub-movement stage of "324C+1D" movement jump and squat, which was the shortest time among the three athletes.

1.1.1.3 Time analysis of take-off, push and stretch sub-stage.

From the time of the sub-movement stage of take-off, push and stretch (see Table 4), the average time of the national athletes in the sub-movement stage of "324C+1D" movement is 0.21s, and the standard deviation is 0.03s. Athlete A took 0.18s to complete the sub-movement stage of "324C+1D" movement take-off and push, which was the shortest time among the three athletes. Athlete C took 0.23s to complete the sub-movement stage of "324C+1D" movement take-off and push, which was the longest time among the three athletes.

1.1.2 Link motion characteristics

1.1.2.1 Peak velocity characteristics of swing arm

Table 5 Peak swing arm speed during takeoff (m/s)

Joint / Athlete	Left arm	Right arm
A	10. 76	10. 94
B	13. 56	12. 03
C	11. 33	10. 56
$\overline{X} \pm S$	11. 88±1. 48	11. 18±0. 76

As can be seen from Table 5, the average value of the peak swing arm speed of the left wrist node of the national athletes in the jumping stage is 11.88m /s, and the standard deviation is 1.48m /s. The mean value and standard deviation of the peak velocity of the swing arm of the right wrist node are 11.18 m/s and 0.76 m/s. The peak speed of the swinging arm of the left wrist node is higher than that of the right wrist node, mainly because the rotation direction of the "324C+1D" action is to rotate clockwise along the vertical axis, and the rotation speed of the left arm is slightly higher. However, the personalized jumping characteristics of top athletes are different, and there will be A special situation like movement A, and the swinging arm speed of the right wrist node is higher than that of the left wrist node.

1.1.2.2 Peak characteristics of shoulder-hip torsion Angle

Table 6 Peak shoulder-hip torsion Angle in run-up start stage (°)

Athlete	shoulder and hip torsion Angle in run-up stage	shoulder and hip torsion Angle in take-off stage
A	44.10	73.41
B	46.13	56.29
C	63.02	61.25
$\overline{X} \pm S$	51.08±10.39	63.65±8.81

1.1.2.2.1 Peak analysis of shoulder-hip torsion Angle during run-up

As can be seen from Table 6, the peak average value of shoulder-hip torsion Angle of national athletes in the run-up stage of "324C+1D" is 51.08°, and the standard deviation is 10.39°. According to the rules of martial arts routine competition, martial arts athletes are required to run within 4 steps, athletes generally increase the stride length as much as possible to improve speed, and the larger stride length forms a larger shoulder and hip torsion Angle.

1.1.2.2.2 Peak analysis of shoulder-hip torsion Angle during takeoff

As can be seen from Table 6, the average peak value of shoulder-hip torsion Angle of national athletes in the take-off stage of "324C+1D" movement is 63.65°, and the standard deviation is 8.81°. Because the "324C+1D" action needs to complete 720° body rotation in the air, the take-off stage should be fully prepared for air rotation, and form a larger shoulder and hip torsion Angle as far as possible before the jumping foot leaves the ground, which is more conducive to the completion of the air rotation action. From the data in Table 3, it can be found that the shoulder and hip torsion angles of the three national athletes in the take-off stage are between 56° and 74°, and they all successfully completed the movements, which provides an important reference index for the wushu routine athletes to complete the take-off movement.

1.1.2.3 Shoulder and foot torsion Angle characteristics

Table 7 Shoulder and foot torsion Angleat take-off stage (°)

Athlete	Shoulder and foot twist Angle at take-off stage
A	99.59
B	89.80
C	82.41
$\overline{X} \pm S$	90.60±8.62

As can be seen from Table 4, the average shoulder-foot torsion Angle of national athletes at the time of departure from the ground after completing the "324C+1D" movement is 90.60°, and the standard deviation is 8.82°. Because the "324C+1D" action needs to complete 720° body rotation in the air, the take-off stage should be fully prepared for air rotation, and the larger shoulder and foot torsion Angle should be formed as far as possible before the jumping foot leaves the ground, which is more conducive to the completion of the air rotation action. From the data in Table 4, it can be found that the shoulder and foot torsion Angle of the three national athletes in the take-off stage is between 82° and 100°, and they all successfully completed the movement, which provides an important reference index for the wushu routine athletes to complete the take-off movement.

1.1.2.4 Angle characteristics of ankle, knee and hip joints during take-off and extension

1.1.2.4.1 Analysis of Angle characteristics of left and right ankle joints during take-off, push and stretch

Table 8 Angle of left and right ankle joints during take-off and extension (°)

Athlete	Left ankle		Right ankle	
	Jump squat	Time off ground	Jump squat	Time off ground
A	76.42	148.18	91.71	148.19
B	101.64	121.56	100.84	138.48
C	101.17	81.16	91.02	105.26
$\overline{X} \pm S$	93.08±14.43	116.97±33.75	94.52±5.48	130.64±22.51

From the Angle difference of the left and right ankles (see Table 8), the average Angle of the left ankle and standard deviation of the right ankle at the time of squat in the take-off stage of the "324C+1D" movement are 93.08° and 14.43°, and the average Angle of the right ankle and standard deviation of 5.48° respectively. The average Angle of the left ankle and the standard deviation of the right ankle are 116.97° and 33.75° respectively, and the average Angle of the right ankle and the standard deviation of the right ankle are 130.64° and 22.51° respectively. The Angle characteristics of the left and right ankle joints of the national athletes in the take-off stage of "324C+1D" movement are as follows: there is little difference in the Angle of the left and right ankle joints at the lowest moment of the take-off squat; The Angle of the right ankle is significantly greater than that of the left ankle at the time of takeoff from the ground.

1.1.2.4.2 Analysis of the Angle of the two knee joints at the moment of takeoff and squat and the Angle of the two knees at the moment of departure from the ground

Table 9 Angle of left and right knee joints during take-off and extension（°）

Athlete	Left knee		Right knee	
	Jump squat	Time off ground	Jump squat	Time off ground
A	108.39	170.4	92.26	174.36
B	98.42	148.91	79.16	166.57
C	112.09	103.48	83.16	116.25
$\overline{X} \pm S$	103.30±7.07	140.93±34.71	84.86±6.71	152.39±31.54

From the Angle difference of the left and right knee joints (see Table 9), the average Angle of the left knee joint and the standard deviation of the right knee joint are 103.30° and 7.07° respectively, and the average Angle of the right knee joint and the standard deviation of the right knee joint are 84.86° and 6.71° respectively when the national athletes squat in the take-off stage of "324C+1D" movement. The average Angle and standard deviation of the left knee joint are 140.93° and 34.71° respectively, while the average Angle and standard deviation of the right knee joint are 152.39° and 31.54° respectively. The Angle of the left and right knee joints of the national athletes in the take-off stage of "324C+1D" movement is as follows: the

Angle of the right knee joint is smaller than that of the left knee joint at the lowest moment of the squat; The Angle of the right knee joint is greater than that of the left knee joint at the time of takeoff from the ground.

1.1.2.4.3 Analysis of joint Angle characteristics of left and right hip joints at the lowest moment of center of gravity and off the ground

Table 10 Left and right hip joint angles during take-off and extension (°)

Athlete	Left hip		Right hip	
	Jump squat	Time off ground	Jump squat	Time off ground
A	139. 93	166. 28	90. 01	166. 03
B	100. 22	139. 3	65. 42	147. 94
C	105. 91	110. 86	66. 27	117. 10
$\overline{X} \pm S$	115. 35±21. 47	138. 81±27. 71	73. 90±13. 96	143. 69±24. 74

From the Angle difference of the left and right hip joints (see Table 10), the average Angle of the left hip joint and the standard deviation of the left hip joint are 115.35° and 21.47° respectively, and the average Angle of the right hip joint and the standard deviation of the right hip joint are 73.90° and 13.96° respectively at the time of the national athletes' squat during the take-off stage of the "324C+1D" movement. The mean Angle and standard deviation of the left hip joint are 138.81° and 27.71° respectively, while the mean Angle and standard deviation of the right hip joint are 143.69° and 27.74° respectively. The Angle of the left and right hip joints of the national athletes in the take-off stage of "324C+1D" movement is as follows: the Angle of the right hip joint is obviously smaller than that of the left hip joint at the lowest moment of the squat; The right hip Angle is greater than the left hip Angle at the time of takeoff.

1.1.3 Center of gravity motion characteristics

1.2.1.3.1 Center of gravity speed characteristics in the run-up direction

Table 11 Center of Gravity speed in the run-up direction (m/s)

Athlete \ Action moment	Run-up (peak)	End of run-up	Time off ground
A	1.96	1.57	0.71
B	2.99	2.84	0.59
C	2.81	2.73	1.11
$\overline{X} \pm S$	2.59±0.55	2.38±0.70	0.80±0.27

From the point of view of the center of gravity velocity in the run-up direction (see Table 11), the average peak value of the center of gravity velocity in the run-up direction of the national athletes in the run-up stage after completing the "324C+1D" movement is 2.59m /s, and the standard deviation is 0.55m /s. At the end of the "324C+1D" run-up, the average speed of the center of gravity in the run-up direction is 2.38 m/s, and the standard deviation is 0.70 m/s. The average value and standard deviation of the center of gravity velocity of the national athletes in the run-up direction at the time of take-off from the ground after completing the "324C+1D" movement are 0.80m/s and 0.27m /s. The characteristics of the center of gravity velocity in the run-up direction of the national athletes in the run-up stage of the "324C+1D" movement are as follows: the center of gravity movement speed achieved in the run-up stage decreases rapidly in the take-off stage, which is in line with the general characteristics of the run-up start action, and is ready for the conversion of kinetic energy in the run-up stage into the take-off potential energy.

1.2.1.3.2 Peak characteristics of vertical velocity of the center of gravity

Table 12 Peak vertical velocity of the center of gravity in the take-off stage (m/s)

Athlete \ Action stage	Jump squat	Jump and push
A	-1.82	2.90
B	-1.80	3.27
C	-1.45	2.44
$\overline{X} \pm S$	-1.69±0.21	2.87±0.42

According to the peak value of vertical speed of the center of gravity in the take-off stage (see Table 12), the average peak value of vertical speed of the center of gravity of national athletes in the squat stage of take-off after completing the "324C+1D" movement is -1.69m /s, and the standard deviation is 0.21m/s. The average peak vertical velocity of the center of gravity of national athletes in the "324C+1D" take-off and push stage is 2.87m /s, and the standard deviation is 0.42m /s.

The characteristics of the vertical speed peak value of national athletes in the take-off stage of "324C+1D" are as follows: the vertical speed peak value of the gravity center in the take-off stage is greater than that in the take-off squat stage.

1.2.1.3.3 Vertical movement distance characteristics of the center of gravity

Table 13 Vertical movement distance of Center of gravity in take-off stage (m)

Action stage / Athlete	Jump squat	Jump and push
A	0. 28	0. 36
B	0. 30	0. 36
C	0. 19	0. 11
$\overline{X} \pm S$	0. 26±0. 06	0. 28±0. 14

From the vertical movement distance of the center of gravity in the take-off stage (see Table 13), the average vertical movement distance of the center of gravity in the squat stage of the national athletes completing the "324C+1D" movement is 0.26m, and the standard deviation is 0.06m. In the "324C+1D" movement, the average vertical movement distance of the center of gravity is 0.28m, and the standard deviation is 0.14m.

The characteristics of the vertical movement distance of the center of gravity in the take-off stage of the national athletes completing the "324C+1D" action are as follows: the vertical movement distance of the center of gravity in the take-off and push and stretch stage is not much different from the vertical movement distance of the center of gravity in the take-off and squat stage.

1.2.1.3.4 Center of gravity lifting Angle characteristics at time of liftoff

Table 14 Center of gravity lifting Angle at liftoff (°)

Athlete	Center of gravity lifting Angle at take-off stage
A	75. 1
B	77. 79
C	65. 18
$\overline{X} \pm S$	72. 69±6. 64

From the lifting Angle of the center of gravity at the time of lifting off the ground in the take-off stage (see Table 14), the average lifting Angle of the center of gravity at the time of lifting off the ground in the jumping stage of the national athletes completing the "324C+1D" movement is 72.69°, and the standard deviation is 6.64°.

The characteristics of the center of gravity lifting Angle of the take-off stage of the national athletes completing the "324C+1D" action are as follows: The center of gravity lifting Angle of the take-off stage is not very different from the ground, mainly concentrated between 65 -- 78°.

1.1.4 Peak characteristics of ground vertical reaction force

Table 15 Peak value of ground vertical reaction force during take-off and extension

Athlete	Peak vertical ground reaction force (N)	Weight (KG)	Ground vertical reaction relative value (BW)	$\overline{X} \pm S$
A	2027. 51	59	34. 36	
B	2577. 51	64	40. 27	38. 63±3. 73
C	2474. 96	60	41. 25	

Note: The index shown in Table 12 is the value obtained from the actual force (N) tested by the force measuring table/the Weight of the athlete (KG), the unit is BW (Body Weight).

According to the peak value of the ground vertical reaction force (see Table 15) in the take-off, push and stretch stage, the average ground vertical reaction force of national athletes in the take-off, push and stretch stage after completing the "324C+1D" movement is 38.63BW, the standard deviation is 3.73BW.

The ground reaction force characteristics of national athletes in the take-off, push and stretch stage of "324C+1D" action are as follows: the ground vertical reaction force in the take-off, push and stretch stage is 34-- 42BW.

1.1.5 The analysis of myoelectric characteristics

According to the test results, not all of the 12 muscles selected for testing in this movement stage participated in the work, and only part of the muscles showed activation state. In this study, only the muscles showing activation state were selected for muscle activation sequence (activation time) analysis and integrated electromyography analysis.

1.1.5.1 Analysis of activation sequence (activation time) of relevant muscles during the take-off stage

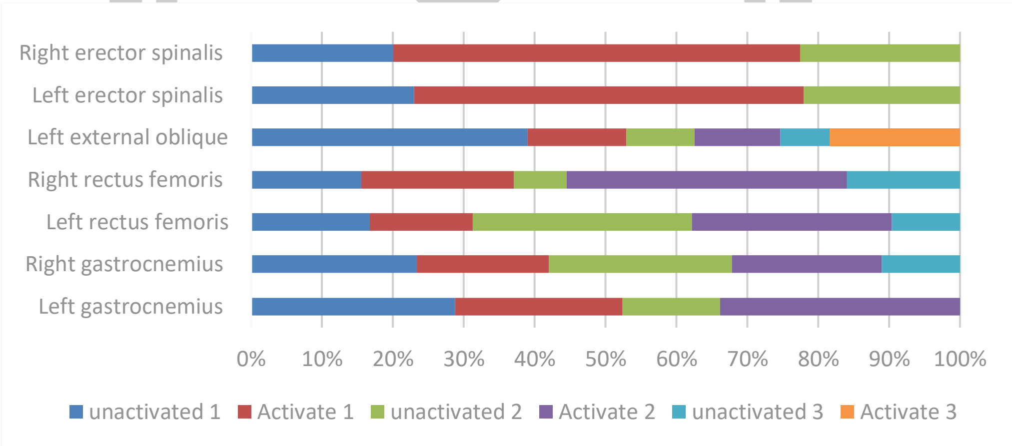

Figure 10 Muscle activation sequence of athlete A at the take-off stage

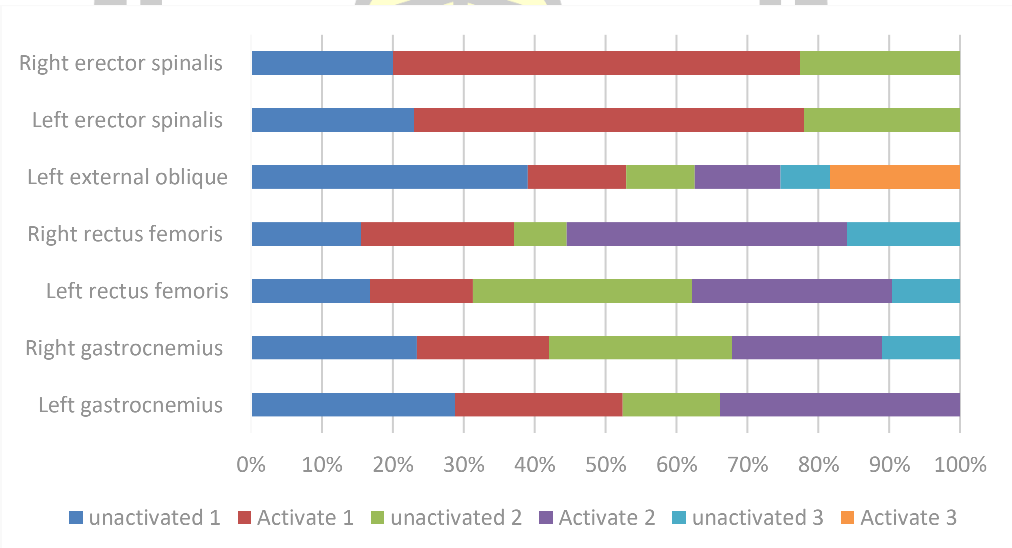

Figure 11 Muscle activation sequence of athlete B during takeoff

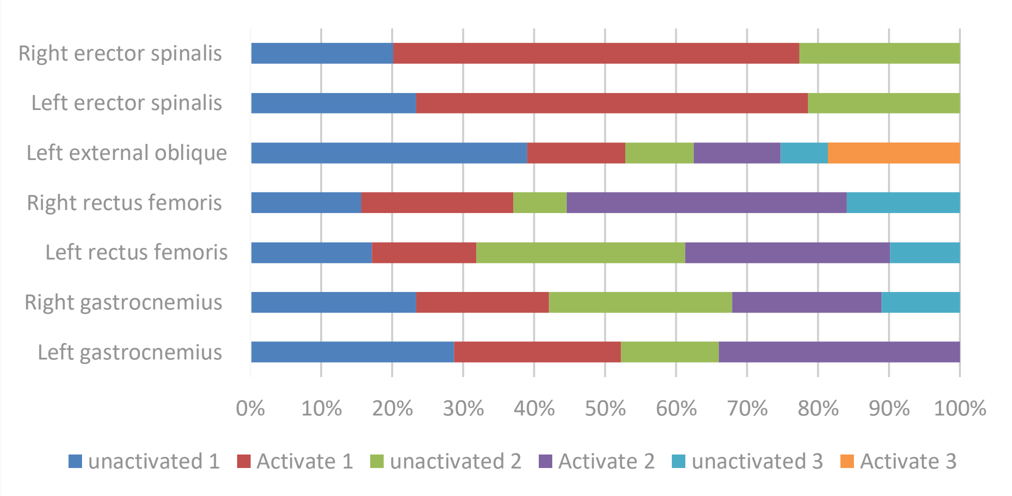

Figure 12 Muscle activation sequence of athlete C during takeoff

From the activation sequence (activation time) of relevant muscles of national athletes in the take-off stage of "324C+1D" movement (see Figure 10, Figure 11, Figure 12), the relevant muscle groups selected in this study did not reach the activated state at the beginning of the take-off stage, and with the continuous decline of the center of gravity, The rectus femoris muscle of the right leg, the rectus femoris muscle of the left leg, the external oblique muscle of the right side and the external oblique muscle of the left side are activated successively to regulate the height of the center of gravity and body posture. The medial head of gastrocnemius muscle of right leg and medial head of gastrocnemius muscle of left leg were activated relatively late. The activation time of the left external oblique muscle was the latest, but the activation time was until the end of the jump phase.

1.1.5.2 Analysis of integrated EMG value of relevant muscles in the take-off stage

Table 16 Integrated EMG values of relevant muscle groups at the take-off stage (μVs)

Athlete / Muscle	A	B	C	$\overline{X} \pm S$
Right gastrocnemius	1318. 55	1365. 23	1309. 34	1331. 04±29. 97
Left rectus femoris	2455. 66	2474. 38	2438. 47	2456. 17±17. 96
Right rectus femoris	2838. 46	2877. 69	2830. 55	2848. 90±25. 24

Left external oblique	784.25	797.61	778.82	786.89±9.67
Left erector spinalis	1952.84	1997.63	1944.39	1964.95±28.61
Right erector spinalis	2165.38	2214.54	2143.12	2174.35±36.54

From the point of view of the integrated EMG value of the relevant muscles of the national athletes in the take-off stage of the "324C+1D" movement (see Table 16), the average value of the integrated EMG value of the gastrocnemius muscle of the left leg of the national athletes is 2274.47μVs, and the standard deviation is 5.25μVs. The mean and standard deviation of the integrated EMG value of the gastrocnemius of the right leg were 1331.04μVs and 29.97μVs. The mean and standard deviation of the integrated EMG value of the left thigh rectus muscle of national athletes were 2459.17 μVs and 17.96μVs. The mean and standard deviation of the integrated EMG value of the right thigh rectus muscle were 2848.90μVs and 25.24μVs. The mean and standard deviation of the integrated EMG value of the left external oblique muscle of national athletes were 786.89μVs and 9.67μVs. The mean value and standard deviation of the integrated EMG value of the left vertical spinal muscle of national athletes were 1964.95μVs and 28.61μVs. The mean and standard deviation of the integrated EMG values of the right vertical spinal muscle were 2174.35μVs and 36.54μVs.

The integrated EMG value of the medial head of gastrocnemius of the left leg was significantly greater than that of the medial head of gastrocnemius of the right leg in the take-off stage of the "324C+1D" movement. The integrated EMG value of the right thigh rectus is greater than that of the left thigh rectus. There was little difference in the integrated EMG values between the left and right vertical spinal muscles.

1.1.6 Summary of technical characteristics of run-up and take-off stage

From the point of view of the indicators of the run-up and take-off stage of the "324C+1D" movement of the national athletes, their technical characteristics are mainly:

(1) The "324C+1D" movement does not have high requirements for the run-up speed in the run-up stage, but appropriately increasing the center of gravity speed in the run-up direction within this speed range may still be conducive to the completion of the "324C+1D" movement.

(2) The center of gravity speed in the run-up direction loses a lot at the time of departure from the ground, and the take-off and push stage is mainly manifested as

the increase of vertical speed, so the center of gravity speed difference in different directions determines the center of gravity lifting Angle at the time of departure from the ground to be closer to 90°, so that the center of gravity movement trajectory of "324C+1D" action in the air stage is approximately straight up and down.

(3) Appropriately increase the shoulder and hip torsion Angle, accelerate the swing arm speed, and increase the shoulder and foot torsion Angle at the moment of departure from the ground, which is conducive to the completion of the athlete's "324C+1D" action.

(4) Accelerating the squat speed of the center of gravity in the vertical direction in the take-off stage, shortening the take-off time of the squat and push and stretch stage, and increasing the ground vertical reaction force in the take-off and push and stretch stage are conducive to the completion of the "324C+1D" movement.

(5) Within a certain range, increasing the vertical speed of the center of gravity and the vertical reaction force of the ground during the take-off and push phase is one of the conditions to ensure that the athletes complete the "324C+1D" action. However, when the vertical speed of the center of gravity and the vertical reaction force of the ground reach a certain level, continuing to increase or slightly decrease is not the key to determining whether the athlete can complete the "324C+1D" action.

(6) The ankle and knee joints are not squatting as low as possible, but in a moderate range; The right ankle and right knee are more fully extended than the left ankle and left knee at the moment of lifting. The joint fan Angle of the right knee participating in the push and stretch in the take-off stage is larger than that of the left knee; The right hip joint is not sufficiently extended at the time of departure from the ground after completing the "324C+1D" maneuver. In addition, because the vertical movement distance of the center of gravity in the jumping stage is affected by the Angle change of the lower limb joints, the vertical movement distance of the center of gravity in this movement stage also shows that the larger the better or the smaller the better, but in a moderate range.

(7) From the case analysis of myoelectric characteristics, there was a great difference in the exertion degree of the extensor muscles of the left and right ankle knee joints at the take-off stage, in which the medial head of the gastrocnemius muscle of the left leg and the rectus femoris muscle of the right leg played the main role of pushing and extending; In the jumping stage, increasing the strength of the external oblique muscle of the abdomen and other trunk rotators is conducive to the athletes to complete the difficult air swing. The high difficulty of the air swing lotus

movement has relatively high requirements on the strength of the vertical spine muscle.

1.2 Analysis of technical characteristics of the vacating stage

1.2.1 Time characteristics

Table 17 Time required for vacating phase (s)

Action stage / Athlete	Off the ground to beat	Tap to the ground	The whole flight phase
A	0. 18	0. 49	0. 67
B	0. 15	0. 55	0. 70
C	0. 16	0. 51	0. 67
$\overline{X} \pm S$	0. 16±0. 02	0. 52±0. 03	0. 68±0. 02

1.2.1.1 Total time analysis of the vacating stage

From the total time spent in the air stage (see Table 17), the average time spent in the air stage of the national athletes completing the "324C+1D" movement is 0.68s, and the standard deviation is 0.02s. The total time of the three athletes participating in the test to complete the "324C+1D" movement in the air stage is very close, among which the time of athlete A and athlete C to complete the "324C+1D" movement in the air stage is the same, both are 0.67s, which is the shortest time of the three athletes. Athlete B took 0.70s to complete the air stage of "324C+1D" movement, which was the longest time among the three athletes.

1.2.1.2 Analysis of the time from the ground off stage to the beat stage in the air stage

From the time of the sub-action stage of jumping off the ground to beating (see Table 17), the average time of the national athletes in completing this sub-action stage of the "324C+1D" movement is 0.16s, and the standard deviation is 0.02s. Athlete A took the longest time (0.18s) to complete the sub-movement stage of "324C+1D" movement; Athlete B took 0.15s to complete the sub-movement stage of "324C+1D" movement, which was the shortest time among the three athletes.

1.2.1.3 Analysis of the time from tapping to landing sub-stage

From the time of this sub-movement stage (see Table 17), the average time of national athletes in completing the sub-movement stage of "324C+1D" from beating to landing is 0.52s, and the standard deviation is 0.03s. Athlete B took 0.55s to complete the sub-movement stage of "324C+1D" movement, which was the longest among the three athletes. Athlete A took 0.49s to complete the sub-movement stage of "324C+1D" movement, which was the shortest time among the three athletes.

1.2.2 Link movement characteristics

1.2.2.1 Right leg swing speed characteristics

Table 18 Right leg swing speed in the airborne phase (m/s)

Athlete \ Action moment	pre-beat (Peak value)	Tap time	post-beat (Peak value)
A	11. 29	10. 12	9. 90
B	11. 75	11. 23	11. 03
C	11. 59	11. 79	11. 95
$\overline{X} \pm S$	11. 54±0. 23	11. 05±0. 85	10. 96±1. 03

As can be seen from Table 18, the average peak speed of the right leg swing before the stroke of the "324C+1D" movement in the air stage is 11.54m /s, and the standard deviation is 0.23m /s. The average speed and standard deviation of the right leg swing of the national athletes in the air stage of the "324C+1D" movement is 11.05 m/s, and the standard deviation is 0.85 m/s. The average peak speed and standard deviation of the right leg swing speed after the "324C+1D" movement are 10.96m /s and 1.03m /s respectively. Athlete A and athlete B showed the same characteristics in the swing speed of the right leg in the air stage, that is, the swing speed was the fastest before the stroke, the speed was lower at the moment of the stroke, and then it was lower after the stroke. However, athlete C showed the opposite speed change trend, and these three speeds gradually increased in the air stage. However, from the average change of the right leg swing speed of all athletes in the air stage, the speed still shows a trend of slowing down gradually.

1.2.2.2 Angular velocity characteristics of shoulder axis rotation

Table 19 Angular velocity of shoulder shaft rotation in the unloading stage (°/s)

Athlete \ Action moment	Tap time	post-beat (Peak value)	Landing time
A	505. 86	1709. 88	850. 46
B	695. 00	2463. 82	692. 73
C	629. 06	1828. 29	573. 90
$\overline{X} \pm S$	609. 97±96. 00	2000. 66±405. 45	705. 70±138. 74

As can be seen from Table 19, the average angular velocity of shoulder axis rotation of national athletes at the time of hitting in the air stage of "324C+1D" movement is 609.97°/s, and the standard deviation is 96.00°/s. The average peak angular velocity and standard deviation of the shoulder axis rotation velocity of the national athletes after finishing the "324C+1D" movement in the air stage are 2000.66°/s and 405.45°/s. The average angular velocity and standard deviation of the scapuloaxial rotation of the national athletes at the landing time of the landing stage of the "324C+1D" movement are 705.70°/s and 138.74°/s respectively.

1.2.3 Center of gravity motion characteristics

1.2.3.1 Vertical velocity characteristics of the center of gravity

Table 20 Vertical velocity of the center of gravity in the take-off stage (m/s)

Action moment / Athlete	pre-beat (Peak value)	Tap time
A	2. 72	0. 96
B	3. 14	1. 71
C	2. 95	2. 13
$\overline{X} \pm S$	2. 94±0. 21	1. 60±0. 59

As can be seen from Table 20, the average vertical speed of the center of gravity before the stroke in the air stage of the "324C+1D" movement of national athletes is 2.94m /s, and the standard deviation is 0.21m /s. The average vertical speed of the center of gravity of the national athletes at the time of striking in the air stage of "324C+1D" is 1.60m /s, and the standard deviation is 0.59m /s. The vertical speed of the center of gravity of the three athletes in the air stage showed the same characteristics, that is, the vertical speed of the center of gravity before the stroke was higher than the vertical speed of the center of gravity at the moment of the stroke.

1.2.3.2 Vertical height characteristics of the center of gravity at the time of departure and landing

Table 21 Vertical height of the Center of gravity at the time of departure and landing (m)

Athlete \ Action moment	Time off ground	Landing time
A	1. 20	0. 87
B	1. 13	0. 98
C	0. 89	1. 07
$\overline{X} \pm S$	1. 07±0. 16	0. 97±0. 10

As can be seen from Table 21, the mean value and standard deviation of the vertical height of the center of gravity at the time of lifting off the ground during the "324C+1D" movement of national athletes are 1.07m and 0.16m respectively. The average vertical height of the center of gravity at the landing moment of the national athletes completing the "324C+1D" movement in the air stage is 0.97 meters, and the standard deviation is 0.10 meters. The vertical height of the center of gravity of athlete A and athlete B at the time of departure from the ground was significantly higher than that at the time of landing when they completed the "324C+1D" movement. However, the vertical height of the center of gravity at the time of departure from the ground when athlete C completes the "324C+1D" movement is lower than the vertical height of the center of gravity at the time of landing. From the average point of view, the vertical height of the center of gravity at the time when the three national athletes completed the "324C+1D" movement was higher than the vertical height of the center of gravity at the time of landing.

1.2.3.3 Characteristics of vertical movement distance of center of gravity

Table 22 Vertical movement distance of the Center of gravity in the unloading stage (m)

Athlete	The center of gravity lifts the distance	Fall distance
A	0. 36	0. 70
B	0. 52	0. 67
C	0. 61	0. 43
$\overline{X} \pm S$	0. 50±0. 13	0. 60±0. 15

As can be seen from Table 22, the average vertical lifting distance of the center of gravity of the national athletes in the air stage of completing the "324C+1D" movement is 0.53 meters, and the standard deviation is 0.13 meters. The average vertical fall distance of the center of gravity and standard deviation of the national athletes in the "324C+1D" movement in the air stage are 0.60 meters and 0.15 meters. The vertical lifting distance of the center of gravity of athlete A and athlete B was significantly lower than the vertical falling distance of the center of gravity in the airborne stage of the completion of the "324C+1D" movement. However, the vertical lifting distance of the center of gravity of athlete C was higher than the vertical falling distance of the center of gravity in the airborne stage of the completion of the "324C+1D" movement. From the average point of view, the vertical lifting distance of the center of gravity of the three national athletes in the air stage of completing the "324C+1D" movement is lower than the vertical falling distance of the center of gravity.

1.2.4 Analysis of EMG characteristics

According to the test results, not all of the 12 muscles selected for testing in this movement stage participated in the work, and only part of the muscles showed activation state. In this study, only the muscles showing activation state were selected for muscle activation sequence (activation time) analysis and integrated electromyography analysis.

1.2.4.1 Analysis of activation sequence (activation time) of relevant muscles in the flight stage

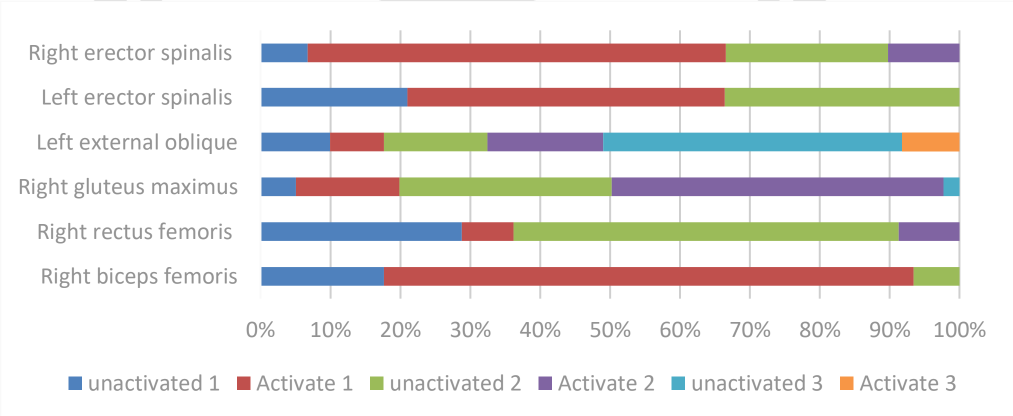

Figure 13 Muscle activation sequence of athlete A during the airborne phase

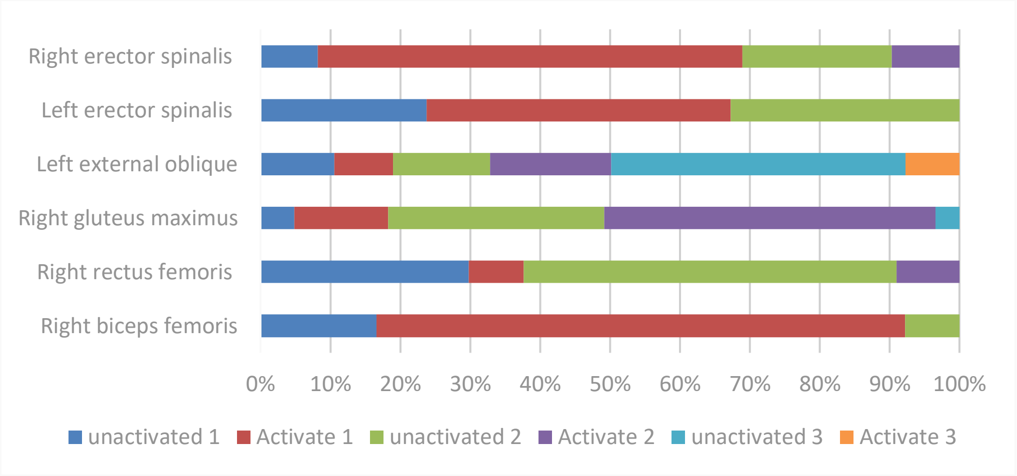

Figure 14 Muscle activation sequence of athlete B during the airborne phase

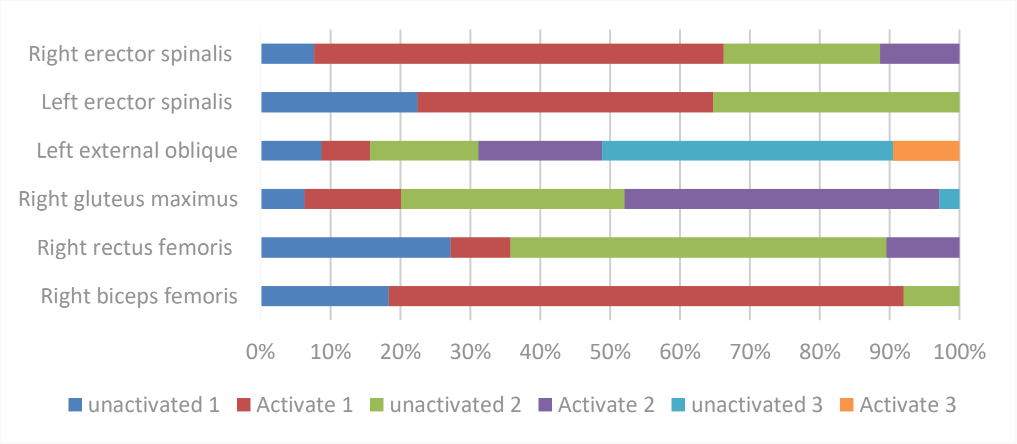

Figure 15 Muscle activation sequence of athlete C during the airborne phase

According to the activation sequence (activation time) of muscles related to the "324C+1D" movement of national athletes (see Figure 13, Figure 14, Figure 15), the left external oblique muscle, the right thigh femoris rectus muscle and the right thigh gluteus maximus were activated first, which indicates that the right leg swings upward and outward while the left external oblique muscle contracts to make the torso in a right-turn posture. Second, the right vertical ridge muscle was activated, and the activation time of the left vertical ridge muscle was later than that of the right vertical ridge muscle, indicating that the swing of the right leg may have an impact on the right vertical ridge muscle, causing the right vertical ridge muscle to be activated first. The biceps femoris of the right leg activates later, but stays active longer.

1.2.4.2 Integrated EMG value of relevant muscles in the flight stage

Table 23 Integrated EMG value of relevant muscle groups in the vacating stage (μVs)

Muscle \ Athlete	A	B	C	$\overline{X} \pm S$
Right biceps femoris	4761. 52	4839. 32	4698. 67	4766. 50±70. 46
Right rectus femoris	1246. 84	1278. 63	1237. 93	1254. 47±21. 40
Right gluteus maximus	732. 14	736. 88	729. 66	732. 89±3. 67
Left external oblique	796. 36	816. 58	788. 96	800. 63±14. 30
Left erector spinalis	2166. 52	2174. 26	2164. 37	2168. 38±5. 20
Right erector spinalis	2213. 62	2242. 31	2209. 64	2221. 86±17. 82

From the point of view of the integrated EMG value of the relevant muscles of the national athletes in the air stage of completing the "324C+1D" movement (see Table 23), the average value of the integrated EMG value of the right biceps femoris of the national athletes is 4766.50μVs, and the standard deviation is 70.46μVs. The mean and standard deviation of the integrated EMG value of the right thigh rectus muscle of national athletes are 1254.47μVs and 21.40μVs. The mean value and standard deviation of right gluteus maximus integral myoelectric value of national athletes were 732.89μVs and 3.67μVs. The mean value and standard deviation of the integrated EMG value of the left external oblique muscle of national athletes were 800.63μVs and 14.30μVs. The mean value and standard deviation of the integrated EMG value of the left vertical spinal muscle of national athletes were 2168.38μVs and 5.20μVs. The mean and standard deviation of the integrated EMG values of the right vertical spinal muscle were 2221.86μVs and 17.82μVs.

National athletes in the "324C+1D" movement in the jumping stage of the right leg biceps integrated EMG value is the largest; The right gluteus maximus had the smallest integrated EMG value. There was little difference in the integrated EMG values between the left and right vertical spinal muscles.

1.2.5 Summary of technical characteristics of the flight stage

From the indicators of the airborne stage of the "324C+1D" movement completed by national athletes, its technical characteristics are mainly:

(1) Increasing the vertical speed of the center of gravity before the stroke, increasing the vertical movement distance of the center of gravity lifting stage and the center of gravity falling stage, extending the air delay time, accelerating the swing speed of the right leg, and moving the moment of the stroke forward to the rapid rising period of the center of gravity lifting as far as possible are conducive to the completion of the "324C+1D" movement of the athlete.

(2) Because the vertical height of the center of gravity at the time of leaving the ground is significantly greater than the vertical height of the center of gravity at the time of landing, the vertical movement distance of the center of gravity in the stage of lifting is significantly less than the vertical movement distance of the center of gravity in the stage of falling, and increasing the vertical movement distance of the center of gravity in the stage of falling is the main way for athletes to complete the "324C+1D" movement at present.

(3) Accelerating the angular rotation speed of the shoulder shaft in the air stage is conducive to the completion of the "324C+1D" action. Among them, increasing the angular rotation speed of the shoulder axis after hitting is the key to complete the "324C+1D" action.

(4) From the case analysis of EMG characteristics, in the air stage of "324C+1D" movement, it may be more important to increase the strength of the right leg lower press muscle group than to increase the strength of the leg lift muscle group; "324C+1D" movement also has relatively high requirements on the strength of the vertical spine muscle in the aerial stage. The integrated myoelectric value of the gluteus maximus muscle of the right leg is small, which may be because the athlete reduces the outward leg swing amplitude to shorten the leg swing time in order to complete the "324C+1D" movement. The integrated myoelectric value of the left external oblique muscle is small, which may be because the reduction of the exertion degree of the gluteus maximus muscle of the right leg affects the exertion degree of the left external oblique muscle to a certain extent. There may be a high correlation between the active muscle group of the right abduction muscle of the right leg and the active muscle group of the right turn of the trunk in the air stage of the "324C+1D" movement.

1.3 Analysis of technical characteristics in landing stage

1.3.1 Link motion characteristics

1.3.1.1 Shoulder and foot torsion Angle feature

Table 24 Shoulder and foot torsion Angleat landing stage (°)

Athlete	Landing stage landing time shoulder-foot torsion Angle
A	22. 78
B	25. 72
C	12. 03
$\overline{X} \pm S$	20. 18±7. 21

As can be seen from Table 24, the average shoulder-foot torsion Angle of national athletes at the landing stage of "324C+1D" movement is 20.18° and the standard deviation is 7.21°. Athlete A and athlete B have close shoulder-foot torsion angles at the landing stage when they complete the "324C+1D" movement, both of which are significantly greater than athlete C's shoulder-foot torsion angles.

1.3.1.2 Angle characteristics of knee sector

Table 25 Knee sector Angle during landing cushion stage (°)

Joint / Athlete	Left knee	Right knee
A	92. 07	32. 85
B	44. 26	20. 24
C	49. 99	10. 82
$\overline{X} \pm S$	62. 11±26. 11	21. 30±11. 05

The knee joint is the main buffer joint after landing, and the knee knee action is done after the foot hits the ground to cushion the impact of the moment of landing. As can be seen from Table 25, in the landing buffer stage of "324C+1D" movement, the average value of the sector Angle of the left knee joint is 62.11° and the standard deviation is 26.11°; the average value of the sector Angle of the right knee joint is

21.30° and the standard deviation is 11.05°. The fan Angle of the left knee joint is larger than that of the right knee joint of the national athletes in the landing buffer stage of the "324C+1D" movement.

1.3.2 Center of gravity motion characteristics

1.3.2.1 Vertical velocity characteristics of the center of gravity at landing time

Table 26 Vertical Velocity of center of gravity at landing time (m/s)

Athlete	Vertical velocity of the center of gravity at the moment of landing
A	−3.45
B	−3.75
C	−2.88
$\overline{X} \pm S$	−3.36±0.44

Note: "-" is the falling speed of the center of gravity.

As can be seen from Table 26, the average vertical speed of the center of gravity at the landing moment of the national athletes completing the "324C+1D" movement is -3.36m /s, and the standard deviation is 0.44m /s. Among them, the national athletes' vertical speed of the center of gravity at the landing moment after completing the "324C+1D" movement is the maximum of -3.75m /s, and the minimum vertical speed of the center of gravity is -2.88m /s.

1.3.2.2 Characteristics of vertical movement distance of center of gravity in landing buffer stage

Table 27 Vertical movement distance of Center of gravity in landing buffer stage (m)

Athlete	The vertical distance of the center of gravity during the landing buffer phase
A	0.35
B	0.42
C	0.56
$\overline{X} \pm S$	0.44±0.11

As can be seen from Table 27, in the landing buffer stage of "324C+1D" movement, the average vertical movement distance of the center of gravity of national athletes is 0.44m, and the standard deviation is 0.11m. Among them, in the landing buffer stage of "324C+1D" movement, the maximum vertical movement distance of the center of gravity is 0.56m, and the minimum vertical movement distance of the center of gravity is 0.35m.

1.3.3 Analysis of EMG characteristics

According to the test results, not all of the 12 muscles selected for testing in this movement stage participated in the work, and only part of the muscles showed activation state. In this study, only the muscles showing activation state were selected for muscle activation sequence (activation time) analysis and integrated electromyography analysis.

1.3.3.1 Analysis of the activation sequence (activation time) of relevant muscles during the landing stage

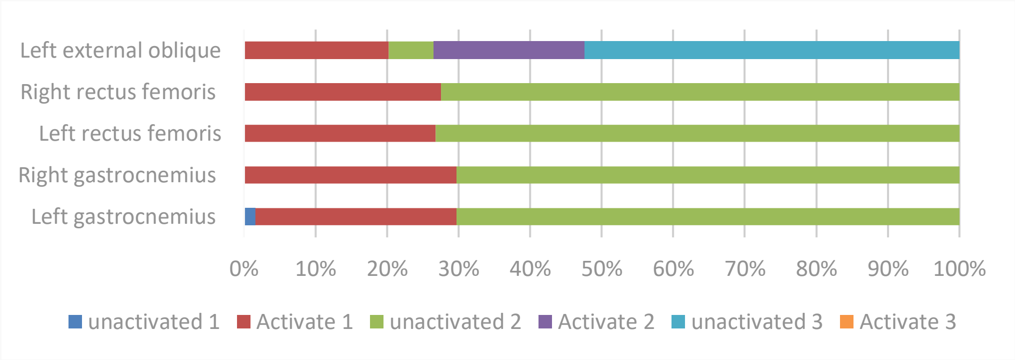

Figure 16 Muscle activation sequence of athlete A at landing stage

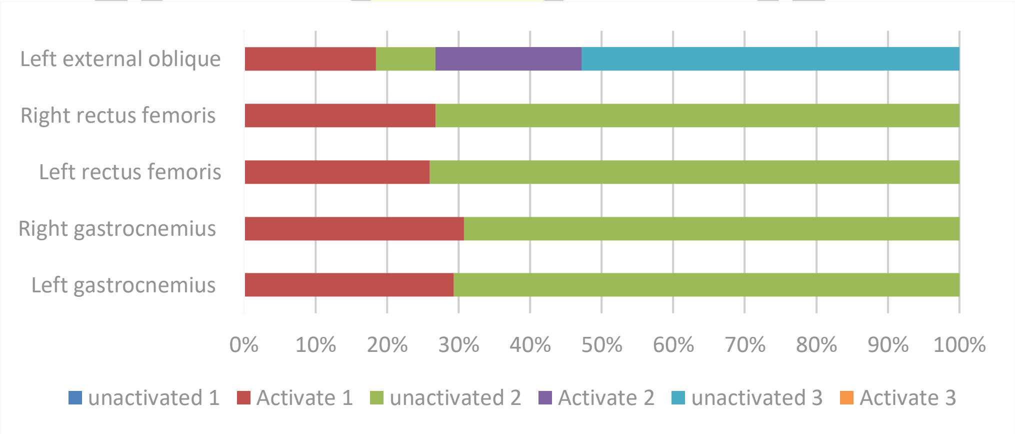

Figure 17 Muscle activation sequence of athlete B at landing stage

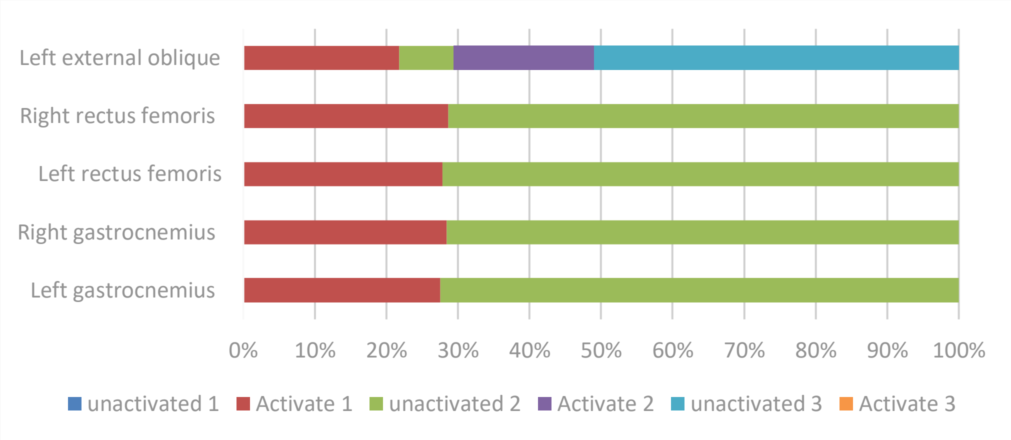

Figure 18 Muscle activation sequence of athlete Cat landing stage

According to the activation sequence (activation time) of muscles related to the "324C+1D" movement of national athletes (see Figure 16, Figure 17, Figure 18), the left external oblique muscle is activated almost simultaneously with the lower extremity extensor muscle in the "324C+1D" movement, and the activation time is equal to or slightly larger than the activation time of the lower extremity extensor muscle. This indicates that the "324C+1D" movement still needs to activate the trunk rotator muscle group to complete the subsequent trunk corner after landing. In the landing stage of the "324C+1D" movement, the activation time of the left and right leg gastrocnemius muscle and the right and left thigh rectus muscle is relatively close, and the activation time is longer.

1.3.3.2 Integrated EMG analysis of relevant muscles at landing stage

Table 28 Integrated EMG values of relevant muscle groups at landing stage (μVs)

Muscle \ Athlete	A	B	C	$\overline{X} \pm S$
Left gastrocnemius	1257. 43	1261. 86	1256. 94	1258. 74±2. 71
Right gastrocnemius	504. 77	519. 68	503. 61	509. 35±8. 96
Left rectus femoris	1237. 63	1247. 62	1236. 86	1240. 70±6. 00
Right rectus femoris	895. 47	903. 23	896. 64	898. 45±4. 18
Left external oblique	584. 64	596. 64	584. 36	588. 55±7. 01

From the point of view of the integrated EMG value of the relevant muscles of the national athletes in the landing stage of the "324C+1D" movement (see Table 28), the average value of the integrated EMG value of the gastromius muscle of the left leg of the national athletes is 1258.74μVs, and the standard deviation is 2.71μVs. The mean and standard deviation of the integrated EMG value of the gastrocnemius of the right leg were 509.35μVs and 8.96μVs. The mean and standard deviation of the integrated EMG value of the left thigh rectus muscle of national athletes were 1240.70 μVs and 6.00μVs. The mean and standard deviation of the integrated EMG values of the right thigh rectus muscle were 898.45μVs and 4.18μVs. The mean and standard deviation of the integrated EMG value of the left external oblique muscle of national athletes were 588.55μVs and 7.01μVs.

In the landing stage of the "324C+1D" movement, the integrated myoelectric of the gastrocnemius of the left leg was significantly greater than that of the gastrocnemius of the right leg. In the landing stage of the "324C+1D" movement, the integrated EMG value of the left thigh rectus femoris is greater than that of the right thigh rectus femoris.

1.3.4 Summary of the technical characteristics of the landing stage

From the perspective of the indicators of the "324C+1D" action in the landing stage, its technical characteristics are mainly:

(1) In the landing stage of the "324C+1D" movement, the athlete will extend the air time by lowering the vertical height of the center of gravity at the moment of landing to obtain a larger rotation Angle, and the impact force at the moment of landing will increase under the action of gravitational acceleration, which will lead to the increase of the vertical ground reaction force borne by the athlete after landing. In addition, the reduction of the height of the center of gravity when landing will also occupy a certain buffer distance, resulting in insufficient buffer after landing.

(2) When the athlete completes the "324C+1D" movement, it is still possible to withstand a large ground reaction force in the landing buffer stage. It may be due to the fact that in order to achieve the technical requirements of stability at the moment of landing, the athletes have almost completed the action of separating the legs and walking before landing in the state of having a large falling distance and falling speed of the center of gravity, which reduces the buffering effect of centrifugal contraction of the lower limbs after landing.

(3) In order to complete the "324C+1D" movement, on the one hand, the trunk rotation speed will be accelerated in the air stage, especially the trunk rotation speed after the stroke. In this state, the athlete may delay the leg splitting time and maintain

the high rotational speed in the air for a longer time in order to complete a larger rotation degree, thus causing the trunk rotation speed at the time of landing to be too fast; In addition, if the rotation Angle completed in the air stage is insufficient, it will also be manifested as a phenomenon such as excessive torsion Angle of the shoulders and feet at the moment of landing. Accompanied by this phenomenon, the left external oblique muscle is activated almost simultaneously with the lower limb extensor muscle in the "324C+1D" movement, and the activation time is equal to or slightly larger than the activation time of the lower limb extensor muscle. This indicates that the "324C+1D" movement still needs to activate the trunk rotator muscle group to complete the subsequent trunk corner after landing.

(4) From the perspective of the knee fan Angle and the EMG characteristics of the femoris rects muscle in the landing stage, the athletes' left knee joint takes on a greater cushioning task than the right knee joint in the landing cushioning stage. In particular, high-level athletes in the landing cushioning stage tend to cushion the increased pressure caused by the difficulty step by increasing the left knee fan Angle and the strength of the extensor muscle group. However, if the vertical height of the center of gravity at the moment of landing is too low, it will lead to the lower limb buffering to the squatting state, which will affect the quality of the movement at the landing stage, and it is easy to form a horse step with the center of gravity too low.

1.4 The summary of the main technical characteristics to "324C+1D" movement complete by National athletes

(1) The running speed of the "324C+1D" movement has little effect on the completion of the movement; The lifting Angle of the center of gravity at the time of take-off is close to 90°. In the take-off stage, the twisting Angle of shoulders and hips should be appropriately increased, the swinging arm speed should be accelerated, the twisting Angle of shoulders and feet at the moment of departure should be increased, the squatting speed of the center of gravity in the vertical direction should be accelerated, the jumping time of squat and push and stretch should be shortened, and the vertical reaction force of the ground should be increased. The medial head of the gastrocnemius muscle of the left leg and the rectus femoris muscle of the right leg should play the main role of push and stretch. It is beneficial for athletes to improve the strength of vertical spine muscle by increasing the strength of external oblique muscle and other trunk rotators.

(2) Increase the vertical speed of the center of gravity before striking, increase the vertical moving distance between the center of gravity lifting stage and the center

of gravity falling stage, extend the air holding time, accelerate the swing speed of the right leg, move the moment of striking forward to the rapid rising stage of the center of gravity lifting as much as possible, accelerate the rotational angular speed of the shoulder axis in the airborne stage, increase the rotational angular speed of the shoulder axis after striking, and increase the strength of the muscle group of the right leg pressing down. Improving the strength of the vertical spine muscle, the active muscle group of the right leg abduction and the active muscle group of the right turn of the trunk are conducive to the completion of the "324C+1D" movement.

(3) In the cushioning stage of the athlete, the left knee joint assumes a greater cushioning task than the right knee joint, and improving the leg strength, especially the strength of the left leg, is conducive to improving the stability of the athlete in completing the movement.

2.The technical characteristics analysis of difficult movements "324C+1D" completed by first level athletes

2.1 Analysis of technical characteristics of run-up and take-off stages

The take-off requirement of the difficult action "324C+1D" is to take off with both feet and complete the run-up within 4 steps, so the run-up speed requirement of this action is not high, and the time characteristics of the run-up stage, the characteristics of the center of gravity movement speed, the swing arm speed and other characteristics have a very small impact on the completion of the movement, which can be ignored. Therefore, the time characteristics, center of gravity movement characteristics and swing arm speed characteristics of the run-up stage were not analyzed in this study.

2.1.1 Time characteristics

Table 29 Time of take-off stage (s)

Action stage / Athlete	Jump squat	Jump and push	Take off
D	0. 13	0. 22	0. 35
E	0. 17	0. 24	0. 41
F	0. 20	0. 30	0. 50
$\overline{X} \pm S$	0. 17±0. 04	0. 25±0. 04	0. 42±0. 08

2.1.1.1 The total time analysis of the take-off stage

From the total time of the take-off stage (see Table 29), the average time of the first-level athletes completing the take-off stage of the "324C+1D" movement is 0.42s, and the standard deviation is 0.08s. Among the three athletes who participated in the test, the total time used to complete the take-off stage of the "324C+1D" movement was 0.35s, which was the shortest among the three athletes. Athlete C took 0.50s to complete the take-off stage of the "324C+1D" movement, which was the longest time among the three athletes.

2.1.1.2 Time analysis of take-off and squat stage;

From the time of the submovement stage of take-off squat (see Table 29), the average time of the submovement stage of take-off squat in the "324C+1D" movement is 0.17s, and the standard deviation is 0.04s. Athlete C took 0.20s to complete the sub-movement stage of "324C+1D" movement jumping and squatting, which was the longest among the three athletes. Athlete A took 0.13s to complete the sub-movement stage of "324C+1D" movement jump and squat, which was the shortest time among the three athletes.

2.1.1.3 Time analysis of take-off, push and stretch sub-stage.

From the time of the sub-movement stage of take-off, push and stretch (see Table 29), the average time of the first-level athletes in the sub-movement stage of "324C+1D" movement is 0.25s, and the standard deviation is 0.04s. Athlete A took 0.22s to complete the sub-movement stage of "324C+1D", which was the shortest time among the three athletes. Athlete C took 0.30s to complete the sub-movement stage of "324C+1D" movement take-off and push, which was the longest time among the three athletes.

2.1.2 Link motion characteristics

2.1.2.1 Peak velocity characteristics of the swing arm

Table 30 Peak swing arm speed during takeoff (m/s)

Joint / Athlete	Left arm	Right arm
D	12. 86	10. 80
E	12. 29	10. 84
F	10. 62	10. 24
$\overline{X} \pm S$	11. 92±1. 16	10. 63±0. 34

As can be seen from Table 30, the average value of the peak swinging arm speed at the left wrist node is 11.92 m/s, and the standard deviation is 1.16 m/s, while the average value of the peak swinging arm speed at the right wrist node is 10.63 m/s, and the standard deviation is 0.34 m/s. The peak speed of the swinging arm of the left wrist node is higher than that of the right wrist node, mainly because the rotation direction of the 324C action is to rotate clockwise along the vertical axis, and the rotation speed of the left arm is slightly higher.

2.1.2.2 Peak characteristics of shoulder-hip torsion Angle

Table 31Peak value of shoulder-hip torsion Angle in run-up start stage (°)

Athlete	Shoulder and hip twist Angle during run-up	Shoulder and hip torsion Angle during takeoff
D	64. 64	83. 73
E	47. 79	68. 56
F	52. 99	82. 12
$\overline{X} \pm S$	55. 14±8. 63	78. 14±8. 33

2.1.2.2.1 Peak value analysis of shoulder-hip torsion Angle during run-up

As can be seen from Table 31, the average peak value of shoulder-hip torsion Angle and standard deviation of the "324C+1D" athletes in the run-up stage are 55.14° and 8.63°. According to the rules of martial arts routine competition, martial arts athletes are required to run within 4 steps, athletes generally increase the stride length as much as possible to improve speed, and the larger stride length forms a larger shoulder and hip torsion Angle.

2.1.2.2.2 Peak value analysis of shoulder-hip torsion Angle during takeoff

As can be seen from Table 31, the average peak value of shoulder-hip torsion Angle of first-level athletes in the take-off stage of "324C+1D" is 78.14°, and the standard deviation is 8.33°. Because the "324C+1D" action needs to complete 720° body rotation in the air, the take-off stage should be fully prepared for air rotation, and form a larger shoulder and hip torsion Angle as far as possible before the jumping foot leaves the ground, which is more conducive to the completion of the air rotation action. From the data in Table 24, it can be found that the shoulder and hip torsion Angle of the three first-level athletes in the take-off stage is between 68° and 84°, and they all successfully completed the movement, which provides an important reference index for the wushu routine athletes to complete the take-off movement.

2.1.2.3 Features of shoulder and foot torsion Angle

Table 32 Shoulder and foot torsion Angle at take-off stage (°)

Athlete	Shoulder and foot twist Angle at take-off stage
D	74.27
E	95.34
F	107.54
$\overline{X} \pm S$	92.38±16.83

As can be seen from Table 32, the average shoulder-foot torsion Angle of first-level athletes at the time of departure from the ground after completing the "324C+1D" movement is 92.38°, and the standard deviation is 16.83°. Because the "324C+1D" action needs to complete 720° body rotation in the air, the take-off stage should be fully prepared for air rotation, and the larger shoulder and foot torsion Angle should be formed as far as possible before the jumping foot leaves the ground, which is more conducive to the completion of the air rotation action. From the data in Table 25, it can be found that the shoulder and foot torsion Angle of the three first-level athletes in the take-off stage is between 74° and 108°, and they all successfully completed the movement, which provides an important reference index for the wushu routine athletes to complete the take-off movement.

2.1.2.4 Angle characteristics of ankle, knee and hip joints during take-off and extension

2.1.2.4.1 Analysis of Angle characteristics of left and right ankle joints during take-off, push and stretch

Table 33 Left and right ankle joint angles during take-off and extension (°)

Athlete	Left ankle		Right ankle	
	Jump squat	Time off ground	Jump squat	Time off ground
D	86.04	141.61	90.27	130.69
E	65.26	70.61	92.27	133.12
F	16.43	10.34	71.88	134.14
$\overline{X} \pm S$	55.91±35.73	74.19±65.71	84.81±11.24	132.65±1.77

From the Angle difference of the left and right ankle joints (see Table 33), the average Angle of the left ankle and the standard deviation of the left ankle at the time of squat in the jumping stage of the "324C+1D" movement are 55.91° and 35.73°, and the average Angle of the right ankle and the standard deviation of the right ankle are 84.81° and 11.24°. The average Angle of the left ankle and the standard deviation of the right ankle are 74.19° and 65.71° respectively, and the average Angle of the right ankle and the standard deviation of the right ankle are 132.65° and 1.77° respectively. The Angle of the left and right ankle joints of the first-level athletes in the take-off stage of "324C+1D" movement is as follows: the Angle of the right ankle is greater than that of the left ankle at the lowest moment of the squat; The Angle of the right ankle is significantly greater than that of the left ankle at the time of takeoff from the ground.

2.1.2.4.2 Analysis of the Angle characteristics of the knee joint at the moment of takeoff and squat and the moment of knee joint off the ground

Table 34 Left and right knee joint angles during take-off and extension (°)

Athlete	Left knee		Right knee	
	Jump squat	Time off ground	Jump squat	Time off ground
D	106. 33	173. 21	98. 73	175. 13
E	124. 74	138. 91	97. 63	152. 42
F	72. 53	167. 34	48. 48	170. 16
$\overline{X} \pm S$	101. 20±26. 48	159. 82±18. 34	81. 61±28. 70	165. 90±11. 94

From the Angle difference of the left and right knee joints (see Table 34), the average Angle of the left knee joint and the standard deviation of the left knee joint are 101.20° and 26.48°, and the average Angle of the right knee joint and the standard deviation of the right knee joint are 81.61° and 28.70° at the time of squat in the jumping stage of the "324C+1D" movement. The average Angle of left knee joint and standard deviation of right knee joint are 159.82° and 18.34° respectively, and the average Angle of right knee joint and standard deviation of right knee joint are 165.90° and 11.94° respectively. The Angle of the left and right knee joints of the first-level athletes in the take-off stage of "324C+1D" movement is as follows: the Angle of the right knee joint is smaller than that of the left knee joint at the lowest moment of the squat; The Angle of the right knee joint is greater than that of the left knee joint at the time of takeoff from the ground.

2.1.2.4.3 Analysis of joint Angle characteristics of left and right hip joints during takeoff and squat time and off the ground time

Table 35 Left and right hip joint angles during take-off and extension (°)

Athlete	Left hip		Right hip	
	Jump squat	Time off ground	Jump squat	Time off ground
D	126. 32	162. 21	80. 49	151. 38
E	125. 2	146. 68	78. 22	151. 04
F	92. 19	166. 57	47. 14	164. 71
$\overline{X} \pm S$	114. 57±19. 39	158. 49±10. 45	68. 62±18. 63	155. 71±7. 80

From the Angle difference of the left and right hip joints (see Table 35), the average Angle of the left hip joint and the standard deviation of the left hip joint are 114.57° and 19.39°, and the average Angle of the right hip joint and the standard deviation of the right hip joint are 68.62° and 18.63° at the time of squatting in the take-off stage of the "324C+1D" movement for first-level athletes. The average Angle and standard deviation of the left hip joint were 158.49° and 10.45° respectively, while the average Angle and standard deviation of the right hip joint were 155.71° and 7.80° respectively. The Angle of left and right hip joints of Level I athletes in the take-off stage of "324C+1D" movement is as follows: the Angle of right hip joints is obviously smaller than that of left hip joints at the lowest moment of squat; The right hip Angle is smaller than the left hip Angle at takeoff.

2.1.3 Center of gravity motion characteristics

2.1.3.1 Center of gravity speed characteristics in the run-up direction

Table 36 Center of Gravity Speed in the run-up direction (m/s)

Action moment / Athlete	Run-up (peak value)	End of run-up	Time off ground
D	2.93	1.91	0.54
E	2.99	2.62	0.97
F	3.06	2.37	0.66
$\overline{X} \pm S$	2.99±0.07	2.30±0.36	0.72±0.22

From the point of view of the center of gravity velocity in the run-up direction (see Table 36), the average peak value of the center of gravity velocity in the run-up direction of the first-level athletes in the run-up stage after completing the "324C+1D" movement is 2.99 m/s, and the standard deviation is 0.07 m/s. At the end of the "324C+1D" run, the average speed of the center of gravity in the run-up direction is 2.30 m/s, and the standard deviation is 0.36 m/s. The average value and standard deviation of the center of gravity velocity in the run-up direction are 0.72m/s and 0.22 m/s for the first-class athletes at the time of take-off from the ground after completing "324C+1D" movement. The characteristics of the center of gravity velocity in the run-up direction of the first-level athletes in the run-up stage of the "324C+1D" movement are as follows: the center of gravity movement speed achieved in the run-up stage decreases rapidly in the take-off stage, which is in line with the general characteristics of the run-up take-off action, and is ready for the conversion of kinetic energy into take-off potential energy.

2.1.3.2 Peak vertical velocity characteristics of the center of gravity

Table 37 Peak vertical velocity of the center of gravity during takeoff (m/s)

Action stage / Athlete	Jump squat	Jump and push
D	−2.81	3.06
E	−1.83	2.75
F	−2.25	3.17
$\overline{X} \pm S$	−2.30±0.49	2.99±0.22

From the point of view of the peak value of vertical speed of the center of gravity in the take-off stage (see Table 37), the average peak value of vertical speed of the center of gravity in the squat stage of the take-off stage after completing the "324C+1D" movement is -2.30 m/s, and the standard deviation is 0.49m/s. The average peak vertical velocity of the center of gravity of national athletes in the "324C+1D" take-off and push stage is 2.99m /s, and the standard deviation is 0.22m /s.

The characteristics of the vertical speed peak value of the center of gravity in the take-off stage of the athletes completing the "324C+1D" movement are as follows: the vertical speed peak value of the center of gravity in the take-off and push and extend stage is greater than that in the take-off and squat stage.

2.1.3.3 Vertical movement distance characteristics of the center of gravity

Table 38 Vertical movement distance of Center of gravity during take-off (m)

Action stage / Athlete	Jump squat	Jump and push
D	0. 38	0. 33
E	0. 29	0. 19
F	0. 33	0. 55
$\overline{X} \pm S$	0. 33±0. 05	0. 36±0. 18

From the vertical movement distance of the center of gravity in the take-off stage (see Table 38), the average vertical movement distance of the center of gravity in the squat stage of the first-level athletes completing the "324C+1D" movement is 0.33m, and the standard deviation is 0.05m. The average vertical distance and standard deviation of the center of gravity in the "324C+1D" jumping stage are 0.36m and 0.18m respectively.

The vertical movement distance of the center of gravity in the take-off stage of the athletes completing the "324C+1D" movement is as follows: there is little difference between the vertical movement distance of the center of gravity in the take-off and push and stretch stage and the vertical movement distance of the center of gravity in the take-off and squat stage.

2.1.3.4 Center of gravity lifting Angle characteristics at time of liftoff

Table 39 Center of gravity lifting Angle at time of liftoff（°）

Athlete	Center of gravity lifting Angle at take-off stage
D	72. 52
E	69. 76
F	68. 27
$\overline{X} \pm S$	70. 18±2. 16

From the lifting Angle of the center of gravity at the time of lifting off the ground in the take-off stage (see Table 39), the average lifting Angle of the center of gravity at the time of lifting off the ground in the take-off stage of the "324C+1D" movement is 70.18° and the standard deviation is 2.16°.

The characteristics of the center of gravity lifting Angle of the take-off stage of the athletes completing the "324C+1D" movement are as follows: the center of gravity lifting Angle of the take-off stage is not very different from the ground, mainly concentrated between 68 and 73°.

2.1.4 Peak characteristics of vertical ground reaction force

Table 40 Peak value of ground vertical reaction force during take-off and extension

Athlete	Peak value vertical ground reaction force (N)	Weight (KG)	Ground vertical reaction relative value (BW)	$\overline{X} \pm S$
D	2043.34	64	31.93	
E	2600.39	82	31.71	32.24±0.74
F	2051.44	62	33.09	

Note: The index shown in Table 12 is the value obtained from the actual force (N) tested by the force measuring table/the Weight of the athlete (KG), the unit is BW(Body Weight).

According to the peak value of the ground vertical reaction force (see Table 40), the average value and standard deviation of the ground vertical reaction force of the first-level athletes in the take-off, push and stretch stage after completing the "324C+1D" movement are 32.24BW and 0.74BW.

The ground reaction force characteristics of Level I athletes in the take-off, push and stretch stage of "324C+1D" are as follows: the ground vertical reaction force in the take-off, push and stretch stage is between 31 and 34BW.

2.1.5 Analysis of EMG characteristics

According to the test results, not all of the 12 muscles selected for testing in this movement stage participated in the work, and only part of the muscles showed activation state. In this study, only the muscles showing activation state were selected for muscle activation sequence (activation time) analysis and integrated electromyography analysis.

2.1.5.1 Analysis of activation sequence (activation time) of relevant muscles during the take-off stage

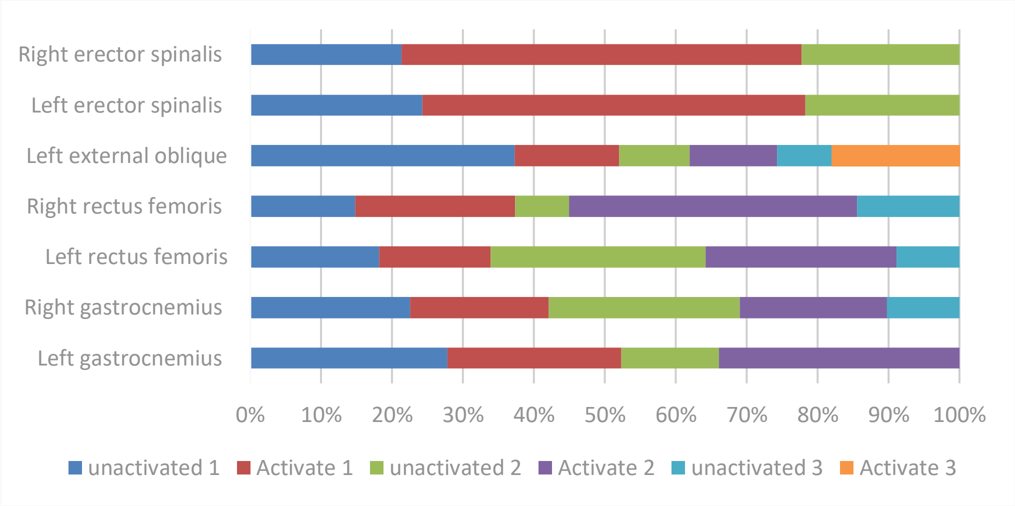

Figure 19 Muscle activation sequence of athlete D during takeoff

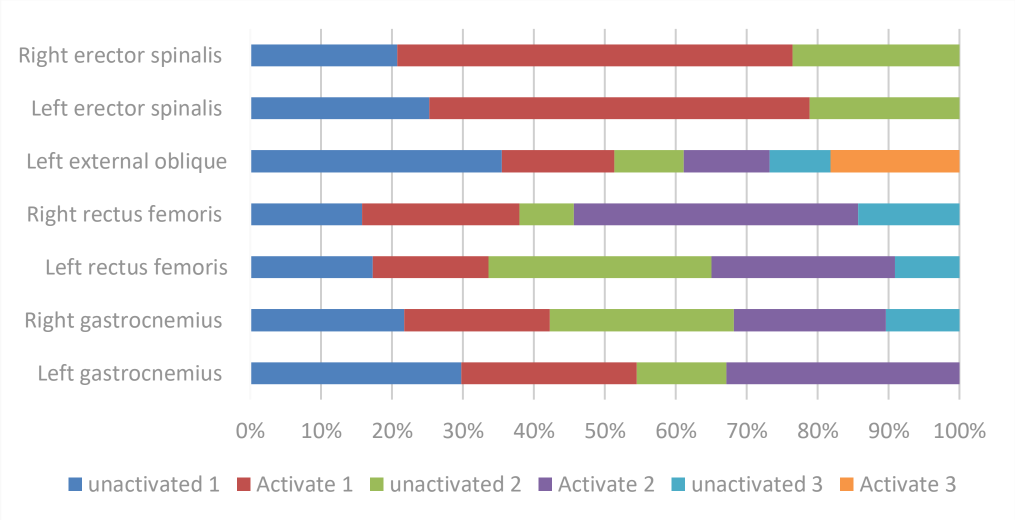

Figure 20 Muscle activation sequence of athlete E during takeoff

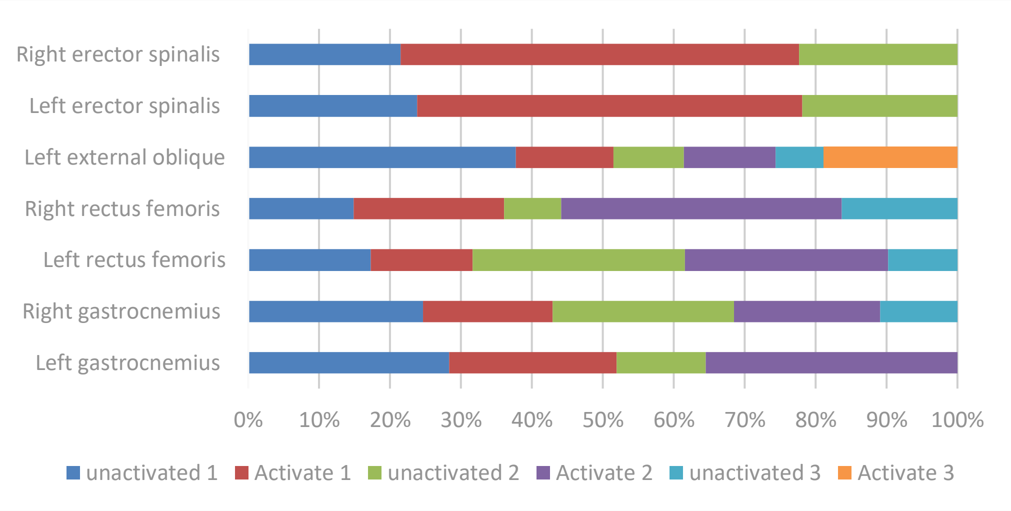

Figure 21 Muscle activation sequence of athlete F during takeoff

From the activation sequence (activation time) of relevant muscles in the take-off stage of the "324C+1D" movement of Level I athletes (see FIG. 19, 20 and 21), the relevant muscle groups selected in this study did not reach the activated state at the beginning of the take-off stage, and with the continuous decline of the center of gravity, The rectus femoris muscle of the right leg, the rectus femoris muscle of the left leg, the external oblique muscle of the right side and the external oblique muscle of the left side are activated successively to regulate the height of the center of gravity and body posture. The medial head of gastrocnemius muscle of right leg and medial head of gastrocnemius muscle of left leg were activated relatively late. The activation time of the left external oblique muscle was the latest, but the activation time was until the end of the jump phase.

2.1.5.2 Analysis of the integrated EMG value of the relevant muscles in the jumping stage

Table 41 Integrated muscle electromyography value in the jumping stage of first-level athletes (μVs)

Muscle \ Athlete	D	E	F	$\overline{X} \pm S$
Left gastrocnemius	2273. 64	2287. 23	2263. 71	2274. 86±11. 81
Right gastrocnemius	1316. 76	1376. 37	1307. 49	1333. 54±37. 38
Left rectus femoris	2451. 49	2486. 74	2436. 76	2458. 33±25. 68
Right rectus femoris	2832. 91	2891. 61	2828. 75	2851. 09±35. 15

Left external oblique	781.79	803.33	776.49	787.20±14.22
Left erector spinalis	1949.18	2003.75	1941.83	1964.92±33.83
Right erector spinalis	2162.71	2223.68	2139.71	2175.37±43.39

From the point of view of the integrated EMG value of the muscle related to the take-off stage of the "324C+1D" movement of the first-level athletes (see Table 41), the average value of the integrated EMG value of the gastromius muscle of the left leg of the first-level athletes is 2274.86μVs, and the standard deviation is 11.81μVs. The mean and standard deviation of the integrated EMG value of the gastrocnemius of the right leg were 1333.54μVs and 37.38μVs. The mean value and standard deviation of the integrated EMG value of the left thigh rectus muscle were 2458.33μVs and 25.68μVs. The mean and standard deviation of the integrated EMG value of the right thigh rectus muscle were 2851.09μVs and 35.15μVs. The mean value and standard deviation of the integrated EMG value of the left external oblique muscle of Grade I athletes were 787.20μVs and 14.22μVs. The mean value and standard deviation of the integrated EMG value of the left vertical spinal muscle were 1964.92μVs and 33.83μVs. The mean and standard deviation of the integrated EMG values of the right vertical spinal muscle were 2175.37μVs and 43.39μVs.

The integrated EMG value of the medial head of the gastrocnemius of the left leg was significantly greater than that of the medial head of the gastrocnemius of the right leg in the take-off stage of the "324C+1D" movement. The integrated EMG value of the right thigh rectus is greater than that of the left thigh rectus. There was little difference in the integrated EMG values between the left and right vertical spinal muscles.

2.1.6 Summary of technical characteristics of run-up and take-off stages

From the point of view of the indicators of the run-up and take-off stage of the "324C+1D" movement, the technical characteristics of the first-level athletes are mainly:

(1) The "324C+1D" movement does not have high requirements for the run-up speed in the run-up stage, but appropriately increasing the center of gravity speed in the run-up direction within this speed range may still be conducive to the completion of the "324C+1D" movement.

(2) The center of gravity speed in the run-up direction loses a lot at the time of departure from the ground, and the take-off and push stage is mainly manifested as the increase of vertical speed, so the center of gravity speed difference in different directions determines the center of gravity lifting Angle at the time of departure from the ground to be closer to 90°, so that the center of gravity movement trajectory of "324C+1D" action in the air stage is approximately straight up and down.

(3) Appropriately increase the shoulder and hip torsion Angle, accelerate the swing arm speed, and increase the shoulder and foot torsion Angle at the moment of departure from the ground, which is conducive to the completion of the athlete's "324C+1D" action.

(4) Accelerating the squat speed of the center of gravity in the vertical direction in the take-off stage, shortening the take-off time of the squat and push and stretch stage, and increasing the ground vertical reaction force in the take-off and push and stretch stage are conducive to the completion of the "324C+1D" movement.

(5) Within a certain range, increasing the vertical speed of the center of gravity and the vertical reaction force of the ground during the take-off and push phase is one of the conditions to ensure that the athletes complete the "324C+1D" action. However, when the vertical speed of the center of gravity and the vertical reaction force of the ground reach a certain level, continuing to increase or slightly decrease is not the key to determining whether the athlete can complete the "324C+1D" action.

(6) The ankle and knee joints are not squatting as low as possible, but in a moderate range; The right ankle and right knee are more fully extended than the left ankle and left knee at the moment of lifting. The joint fan Angle of the right knee participating in the push and stretch in the take-off stage is larger than that of the left knee; The right hip joint is not sufficiently extended at the time of departure from the ground after completing the "324C+1D" maneuver. In addition, because the vertical movement distance of the center of gravity in the jumping stage is affected by the Angle change of the lower limb joints, the vertical movement distance of the center of gravity in this movement stage also shows that the larger the better or the smaller the better, but in a moderate range.

(7) From the case analysis of myoelectric characteristics, there was a great difference in the exertion degree of the extensor muscles of the left and right ankle knee joints at the take-off stage, in which the medial head of the gastrocnemius muscle of the left leg and the rectus femoris muscle of the right leg played the main role of pushing and extending; In the jumping stage, increasing the strength of the

external oblique muscle of the abdomen and other trunk rotators is conducive to the athletes to complete the difficult air swing. The "324C+1D" movement also has relatively high requirements for the strength of the vertical spine muscle.

2.2 Analysis of technical characteristics in the vacating stage

2.2.1 Time characteristics

Table 42 Time required for vacating phase (s)

Action stage / Athlete	Off the ground to beat	Tap to the ground	The whole flight phase
D	0. 19	0. 48	0. 67
E	0. 17	0. 47	0. 64
F	0. 17	0. 55	0. 72
$\overline{X} \pm S$	0. 18±0. 01	0. 50±0. 04	0. 68±0. 04

2.2.1.1 Total time analysis of the vacating phase

From the total time of the airborne stage (see Table 42), the average time of the airborne stage of the "324C+1D" movement for the first-level athletes is 0.68s, and the standard deviation is 0.04s. The total time of the three athletes participating in the test to complete the "324C+1D" movement in the air stage is very close, and the time of athlete E to complete the "324C+1D" movement in the air stage is 0.64s, which is the shortest among the three athletes. Athlete F took 0.72s to complete the airborne phase of the "324C+1D" movement, which was the longest time among the three athletes.

2.2.1.2 Analysis of the time from ground off to beat in the airborne stage

From the time of the sub-movement stage from take-off to slap (see Table 42), the average time of the first-level athletes to complete the sub-movement stage of the "324C+1D" movement is 0.18s, and the standard deviation is 0.01s. Athlete D took the longest time (0.19s) to complete the sub-movement stage of "324C+1D" movement; Athlete E and athlete F both took 0.17s to complete the sub-movement stage of "324C+1D" movement, which was the shortest time among the three athletes.

2.2.1.3 Time analysis from stroke to landing sub-stage

From the time of this sub-movement stage (see Table 42), the average time of Level I athletes in completing the sub-movement stage of "324C+1D" from the stroke to the landing is 0.50s, and the standard deviation is 0.04s. Athlete F took 0.55s to complete the sub-movement stage of "324C+1D" movement, which was the longest among the three athletes. Athlete E took 0.47s to complete the sub-movement stage of "324C+1D" movement, which was the shortest time among the three athletes.

2.2.2 Link movement characteristics

2.2.2.1 Right leg swing speed characteristics

Table 43 Right leg swing Speed in the airborne phase (m/s)

Action moment / Athlete	pre-beat (Peak value)	Tap time	post-beat (Peak value)
D	12. 40	6. 92	7. 89
E	12. 56	12. 01	11. 04
F	10. 27	6. 67	9. 15
$\overline{X} \pm S$	11. 74±1. 28	8. 53±3. 01	9. 36±1. 59

From Table 43, it can be seen that the average peak swinging speed of the right leg of the first-level athletes before beating in the air stage is 11.74m /s, and the standard deviation is 1.28m /s. The average swing speed of the right leg and standard deviation of the athletes in the air stage are 8.53 m/s and 3.01 m/s respectively. The average peak swinging speed and standard deviation of the right leg are 9.36 m/s and 1.59 m/s respectively. Athlete D and athlete F show the same characteristics in the swing speed of the right leg in the air stage, that is, the swing speed is the fastest before the stroke, the slowest at the moment of the stroke, and then accelerate after the stroke. However, athlete E showed a different speed change trend, and the three speeds gradually decreased in the airborne stage. However, from the average change of the right leg swing speed of all athletes in the air stage, the speed still shows a trend of slowing down and then speeding up.

2.2.2.2 Angular velocity characteristics of shoulder shaft rotation

Table 44 Angular velocity of shoulder shaft rotation during the flight stage (°/s)

Athlete \ Action moment	Tap time	post-beat (Peak value)	Landing time
D	445.31	1790.4	632.13
E	580.78	2047.61	852.25
F	693.14	1961.84	457.55
$\overline{X} \pm S$	573.08±124.09	1933.28±130.96	647.31±197.79

As can be seen from Table 44, the average angular velocity of shoulder axis rotation of first-level athletes at the time of hitting in the air stage of "324C+1D" movement is 573.08°/s, and the standard deviation is 124.09°/s. The average peak angular velocity and standard deviation are 1933.28°/s and 130.96°/s respectively for Level I athletes after hitting the "324C+1D" movement in the air stage. The average angular velocity and standard deviation of the angular velocity of the shoulder shaft at the landing time of the airborne stage of the "324C+1D" movement are 647.31°/s and 197.79°/s respectively.

2.2.3 Movement characteristics of center of gravity

2.2.3.1 Vertical velocity characteristics of the center of gravity

Table 45 Vertical velocity of the center of gravity in the take-off stage (m/s)

Athlete \ Action moment	pre-beat (Peak value)	Tap time
D	2.83	1.15
E	2.78	1.40
F	2.74	1.41
$\overline{X} \pm S$	2.78±0.05	1.32±0.15

As can be seen from Table 45, the average value and standard deviation of the vertical speed of the center of gravity before the stroke in the airborne stage are 2.78m

/s and 0.05m /s. The average vertical speed of the center of gravity and standard deviation of the stroke time of the first-class athletes in the air stage are 1.32 m/s and 0.15 m/s. The vertical speed of the center of gravity of the three athletes in the air stage showed the same characteristics, that is, the vertical speed of the center of gravity before the stroke was higher than the vertical speed of the center of gravity at the moment of the stroke.

2.2.3.2 Vertical height characteristics of the center of gravity at the time of departure and landing

Table 46 Vertical height of the Center of gravity at the time of departure and landing (m)

Action moment / Athlete	Time off ground	Landing time
D	1.15	0.88
E	1.07	0.98
F	1.19	0.79
$\overline{X} \pm S$	1.14±0.06	0.88±0.10

As can be seen from Table 46, the average vertical height of the center of gravity at the time of departure from the ground during the take-off stage of the "324C+1D" movement for first-level athletes is 1.14 meters, and the standard deviation is 0.06 meters. The average vertical height of the center of gravity at the landing moment of the landing stage of the "324C+1D" movement is 0.88 meters, and the standard deviation is 0.10 meters. The vertical height of the center of gravity at the time of departure from the ground is higher than the vertical height of the center of gravity at the time of landing when the three level I athletes complete the "324C+1D" movement in the air stage.

2.2.3.3 Vertical movement distance characteristics of gravity center

Table 47 Vertical movement distance of the Center of gravity in the unloading stage (m)

Athlete	The center of gravity lifts the distance	Fall distance
D	0.41	0.68
E	0.43	0.45
F	0.43	0.83
$\overline{X} \pm S$	0.42±0.01	0.65±0.19

As can be seen from Table 47, the average vertical lifting distance of the center of gravity in the airborne stage of the "324C+1D" movement is 0.42 meters, and the standard deviation is 0.01 meters. The average vertical fall distance of the center of gravity and standard deviation of the "324C+1D" are 0.65 meters and 0.19 meters respectively. The vertical lifting distance of the center of gravity of the three national athletes in the air stage of completing the "324C+1D" movement is less than the vertical falling distance of the center of gravity.

2.2.4 Analysis of EMG characteristics

According to the test results, not all of the 12 muscles selected for testing in this movement stage participated in the work, and only part of the muscles showed activation state. In this study, only the muscles showing activation state were selected for muscle activation sequence (activation time) analysis and integrated electromyography analysis.

2.2.4.1 Analysis of activation sequence (activation time) of relevant muscles during the flight stage

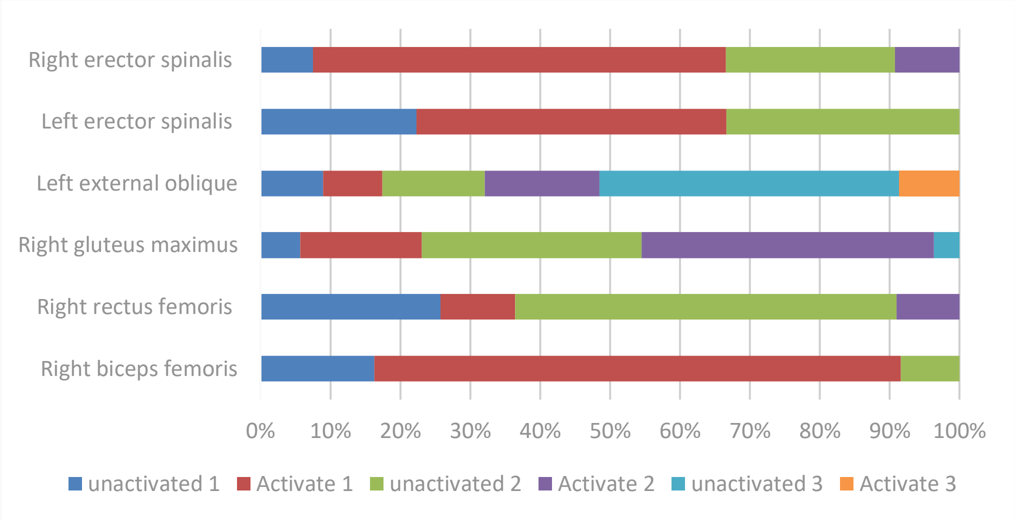

Figure 22 Muscle activation sequence of athlete D during the airborne phase

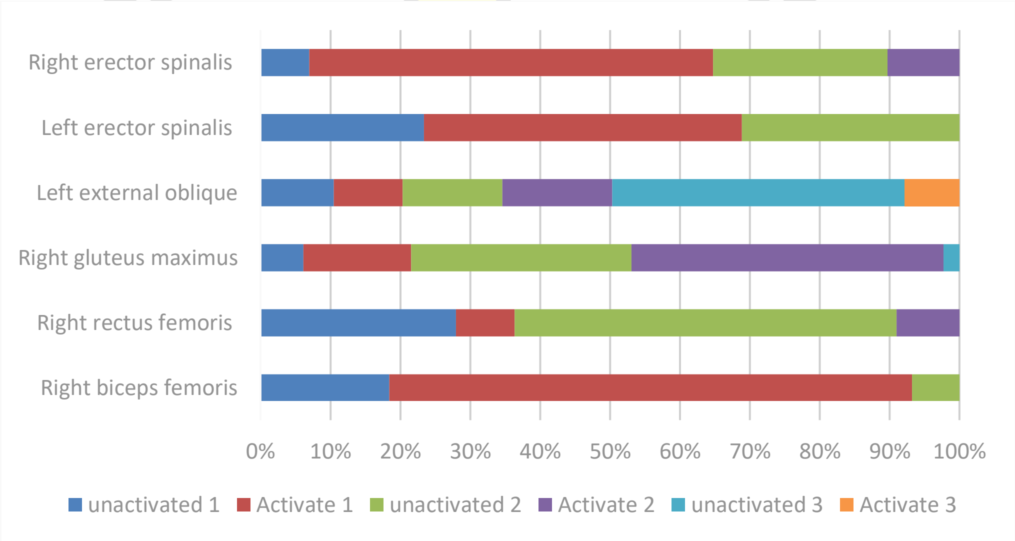

Figure 23 Muscle activation sequence of athlete E during the airborne phase

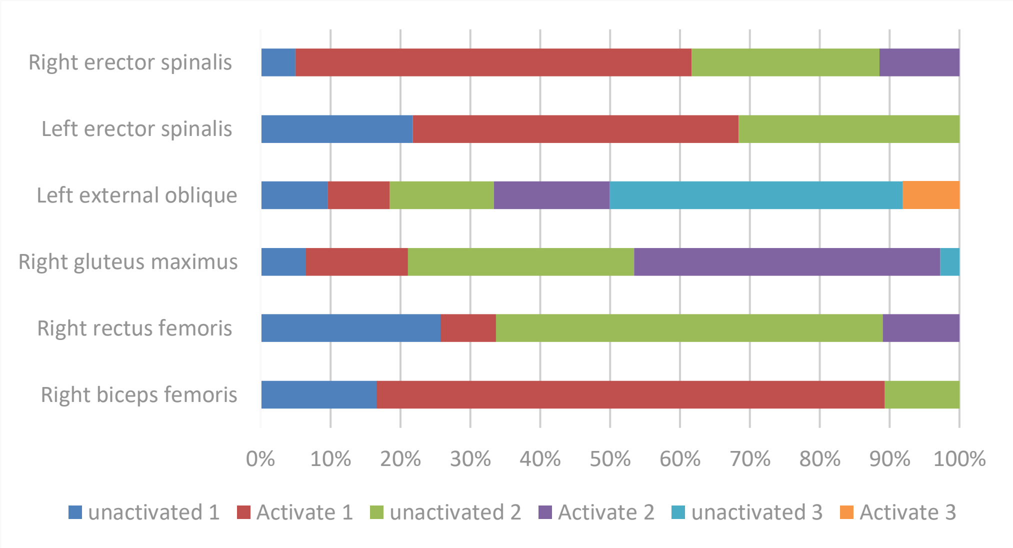

Figure 24 Muscle activation sequence of athlete F during the airborne phase

From the activation sequence (activation time) of muscles associated with the "324C+1D" movement in Level I athletes (see Figure 22, Figure 23, Figure 24), the left external oblique muscle, the right thigh femoris rectus muscle and the right thigh gluteus maximus were activated first, indicating that the right leg swung upward and outward while the left external oblique muscle contracted to put the torso in a right-turn position. Second, the right vertical ridge muscle was activated, and the activation time of the left vertical ridge muscle was later than that of the right vertical ridge muscle, indicating that the swing of the right leg may have an impact on the right vertical ridge muscle, causing the right vertical ridge muscle to be activated first. The biceps femoris of the right leg activates later, but stays active longer.

2.2.4.2 The integrated EMG value of relevant muscles in the vacating stage

Table 48 Integrated EMG value of relevant muscle groups in the vacating stage (μVs)

Muscle \ Athlete	D	E	F	$\overline{X} \pm S$
Right biceps femoris	4757. 43	4858. 42	4664. 74	4760. 20±96. 87
Right rectus femoris	1213. 44	1364. 51	1230. 08	1269. 34±82. 84
Right gluteus maximus	739. 85	834. 62	719. 52	764. 66±61. 43
Left external oblique	802. 70	924. 43	777. 46	834. 86±78. 59
Left erector spinalis	2188. 77	2263. 51	2202. 43	2218. 24±39. 80
Right erector spinalis	2267. 84	2341. 62	2218. 66	2276. 04±61. 89

From the point of view of the integrated EMG value of the muscles related to the "324C+1D" movement of the first-level athletes in the air stage (see Table 48), the average value of the integrated EMG value of the biceps femoris muscle of the right leg of the first-level athletes is 4760.20μVs, and the standard deviation is 96.87μVs. The mean value and standard deviation of the integrated EMG value of the right thigh rectus muscle of Grade I athletes were 1269.34μVs and 82.84μVs. The mean and standard deviation of the integrated myoelectric value of the right gluteus maximus were 764.66μVs and 61.43μVs. The mean and standard deviation of the integrated EMG value of the left external oblique muscle of the first-level athletes were 834.86μ Vs and 78.59μVs. The mean value and standard deviation of the integrated EMG value of the left vertical spinal muscle were 2218.24μVs and 39.80μVs. The mean and standard deviation of the integrated EMG values of the right vertical spinal muscle were 2276.04μVs and 61.89μVs.

The integrated EMG value of the biceps femoris of the right leg is the largest in the jumping stage of "324C+1D". The right gluteus maximus had the smallest integrated EMG value. There was little difference in the integrated EMG values between the left and right vertical spinal muscles.

2.2.5 Summary of technical characteristics of the flight stage

From the indicators of the airborne stage of the "324C+1D" movement completed by the first-level athletes, its technical characteristics are mainly:

(1) Increasing the vertical speed of the center of gravity before the stroke, increasing the vertical movement distance of the center of gravity lifting stage and the center of gravity falling stage, extending the air delay time, accelerating the swing speed of the right leg, and moving the moment of the stroke forward to the rapid rising period of the center of gravity lifting as far as possible are conducive to the completion of the "324C+1D" movement of the athlete.

(2) Because the vertical height of the center of gravity at the time of leaving the ground is significantly greater than the vertical height of the center of gravity at the time of landing, the vertical movement distance of the center of gravity in the stage of lifting is significantly less than the vertical movement distance of the center of gravity in the stage of falling, and increasing the vertical movement distance of the center of gravity in the stage of falling is the main way for athletes to complete the "324C+1D" movement at present.

(3) Accelerating the angular rotation speed of the shoulder shaft in the air stage is conducive to the completion of the "324C+1D" action. Among them, increasing the angular rotation speed of the shoulder axis after hitting is the key to complete the "324C+1D" action.

(4) From the case analysis of myoelectric characteristics, in the air stage of "324C+1D" movement, it may be more important to increase the strength of the right leg lower press muscle group than to increase the strength of the leg lift muscle group; "324C+1D" movement also has relatively high requirements on the strength of the vertical spine muscle in the aerial stage. The integrated myoelectric value of the gluteus maximus muscle of the right leg is small, which may be because the athletes reduce the amplitude of the leg swing outward to shorten the leg swing time in order to complete the more difficult air swing. The integrated myoelectric value of the left external oblique muscle is small, which may be because the reduction of the exertion degree of the gluteus maximus muscle of the right leg affects the exertion degree of the left external oblique muscle to a certain extent, that is, there may be a high correlation between the active muscle group of the right abduction muscle of the right leg and the active muscle group of the right turn of the trunk in the air stage of the air pendulum movement.

2.3 Analysis of technical characteristics in landing stage

2.3.1 Link motion characteristics

2.3.1.1 Shoulder and foot torsion Angle characteristics

Table 49 Shoulder and foot torsion Angleat landing stage (°)

Athlete	Landing stage landing time shoulder-foot torsion Angle
D	35. 93
E	32. 09
F	19. 54
$\overline{X} \pm S$	29. 19±8. 57

As can be seen from Table 49, the average shoulder-foot torsion Angle of first-level athletes at the landing stage of "324C+1D" movement is 29.19° and the standard deviation is 8.57°. The shoulder and foot torsion angles of athlete D and athlete Eat the landing stage of the "324C+1D" movement are close to each other, and both are significantly greater than the shoulder and foot torsion angles of athlete F.

2.3.1.2 Knee sector Angle characteristics

Table 50 Knee sector Angle during landing cushion stage (°)

Athlete \ Joint	Left knee	Right knee
D	87.66	38.97
E	46.29	95.00
F	66.45	47.70
$\overline{X} \pm S$	66.80±20.69	60.56±30.15

The knee joint is the main buffer joint after landing, and the knee knee action is done after the foot hits the ground to cushion the impact of the moment of landing. As can be seen from Table 50, in the landing buffer stage of "324C+1D" movement, the average value of the left knee joint sector Angle is 66.80° and the standard deviation is 20.69°, while the average value of the right knee joint sector Angle is 60.56° and the standard deviation is 30.15°. The fan Angle of the left knee joint was larger than that of the right knee joint when athlete D and athlete F completed the landing cushion stage of "324C+1D" movement. Athlete E completed the "324C+1D" movement landing cushion stage, the left knee joint fan Angle is smaller than the right knee joint.

2.3.2 Center of gravity motion characteristics

2.3.2.1 Vertical velocity characteristics of the center of gravity at landing time

Table 51 Vertical Velocity of center of gravity at landing time (m/s)

Athlete	Vertical velocity of the center of gravity at the moment of landing
A	−3.45
B	−3.75
C	−2.88
$\overline{X} \pm S$	−3.36±0.44

Note: "-" is the falling speed of the center of gravity.

As can be seen from Table 51, the average value of the vertical velocity of the center of gravity at the landing moment of the "324C+1D" movement is -3.17m /s, and the standard deviation is 0.28m /s. Among them, the vertical speed of the center of gravity at the moment of landing after completing the "324C+1D" movement is the maximum of -3.43m /s, and the minimum vertical speed of the center of gravity is -2.87m /s.

2.3.2.2 Characteristics of vertical movement distance of center of gravity in landing buffer stage

Table 52 Vertical movement distance of Center of gravity in landing buffer stage (m)

Athlete	The vertical distance of the center of gravity during the landing buffer phase
D	0.42
E	0.46
F	0.28
$\overline{X} \pm S$	0.39±0.09

As can be seen from Table 52, the average vertical movement distance of the center of gravity in the landing buffer stage of the "324C+1D" movement is 0.39m, and the standard deviation is 0.09m. Among them, in the landing buffer stage of "324C+1D" movement, the maximum vertical movement distance of the center of gravity is 0.46m, and the minimum vertical movement distance of the center of gravity is 0.28m.

2.3.3 Analysis of EMG characteristics

According to the test results, not all of the 12 muscles selected for testing in this movement stage participated in the work, and only part of the muscles showed activation state. In this study, only the muscles showing activation state were selected for muscle activation sequence (activation time) analysis and integrated electromyography analysis.

2.3.3.1 Analysis of the activation sequence (activation time) of relevant muscles during the landing stage

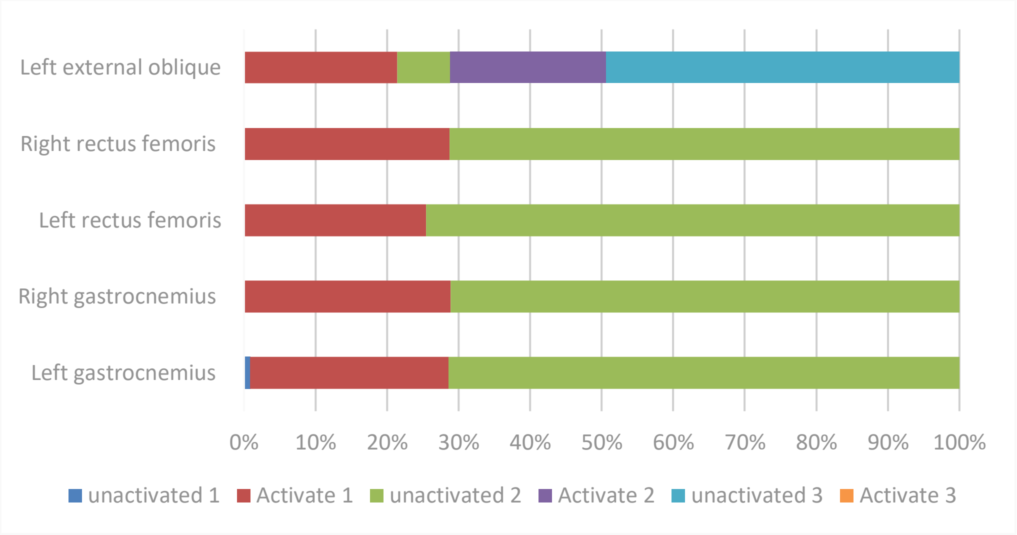

Figure 25 Muscle activation sequence of athlete D at landing stage

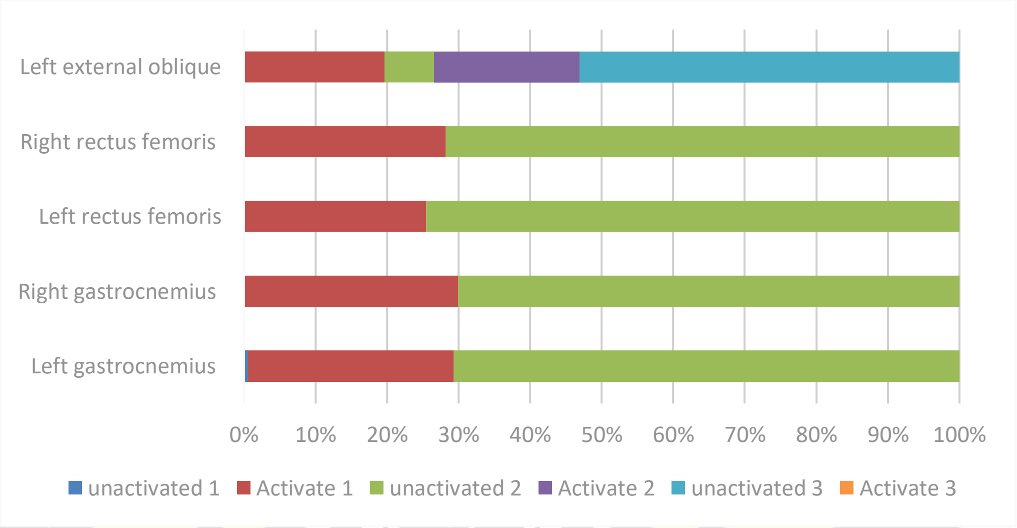

Figure 26 Muscle activation sequence of athlete E at landing stage

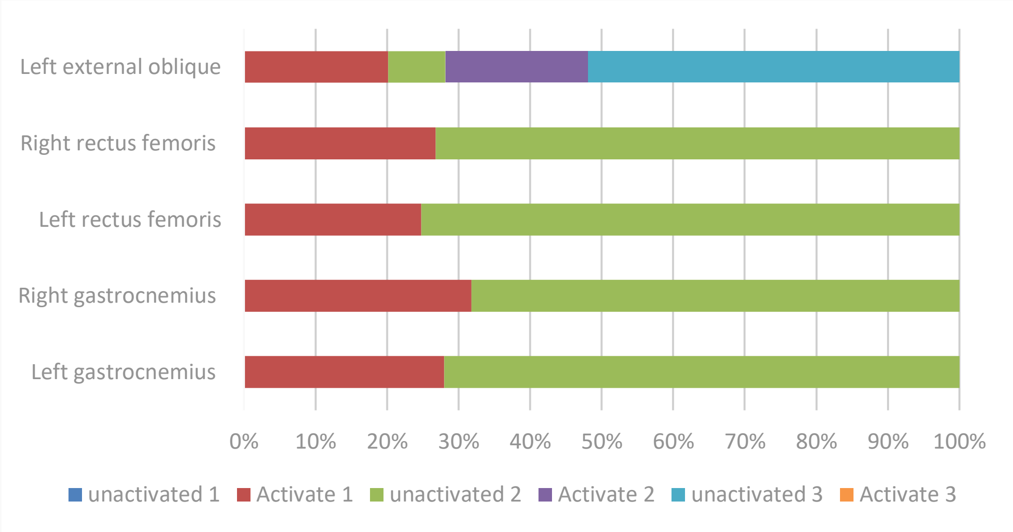

Figure 27 Muscle activation sequence of athlete F at landing stage

According to the activation sequence (activation time) of the muscles in the landing stage of the "324C+1D" movement (see Figure 25, Figure 26, Figure 27), the left external oblique muscle is activated almost simultaneously with the lower extremity extensor muscle in the "324C+1D" movement, and the activation time is equal to or slightly larger than the activation time of the lower extremity extensor muscle. This indicates that the "324C+1D" movement still needs to activate the trunk rotator muscle group to complete the subsequent trunk corner after landing. In the landing stage of the "324C+1D" movement, the activation time of the left and right leg gastrocnemius muscle and the right and left thigh rectus muscle is relatively close, and the activation time is longer.

2.3.3.2 Integrated EMG analysis of relevant muscles at landing stage

Table 53 Integrated EMG values of relevant muscle groups at landing stage (μVs)

Muscle \ Athlete	D	E	F	$\overline{X} \pm S$
Left gastrocnemius	1241. 55	1349. 28	1240. 81	1277. 21±62. 41
Right gastrocnemius	497. 75	599. 71	486. 31	527. 92±62. 43
Left rectus femoris	1212. 19	1305. 24	1175. 64	1231. 02±66. 82
Right rectus femoris	863. 79	967. 32	859. 43	896. 85±61. 07
Left external oblique	561. 46	615. 88	552. 67	576. 67±34. 24

From the point of view of the integrated EMG value of the muscles related to the landing stage of the "324C+1D" movement of the first-level athletes (see Table 53), the average value of the integrated EMG value of the gastrocnemius muscle of the left leg of the first-level athletes is 1277.21μVs, and the standard deviation is 62.41μVs. The mean and standard deviation of the integrated EMG value of the gastrocnemius of the right leg were 527.92μVs and 62.43μVs. The mean value and standard deviation of the integrated EMG value of the left thigh rectus muscle were 1231.02μVs and 66.82μVs. The mean and standard deviation of the integrated EMG values of the rectus femoris muscle of the right leg were 896.85μVs and 61.07μVs. The mean value and standard deviation of the integrated EMG value of the left external oblique muscle of the first-level athletes were 576.67μVs and 34.24μVs.

In the landing stage of the "324C+1D" movement, the integrated myoelectricity of the gastrocnemius of the left leg was significantly greater than that of the gastrocnemius of the right leg. In the landing stage of the "324C+1D" movement, the integrated EMG value of the left thigh rectus femoris is greater than that of the right thigh rectus femoris.

2.3.4 Summary of technical characteristics of landing stage

From the indicators of the landing stage of the "324C+1D" movement completed by first-level athletes, its technical characteristics are mainly:

(1) In the landing stage of the "324C+1D" movement, the athlete will extend the air time by lowering the vertical height of the center of gravity at the moment of landing to obtain a larger rotation Angle, and the impact force at the moment of landing will increase under the action of gravitational acceleration, which will lead to the increase of the vertical ground reaction force borne by the athlete after landing. In addition, the reduction of the height of the center of gravity when landing will also occupy a certain buffer distance, resulting in insufficient buffer after landing.

(2) When the athlete completes the "324C+1D" movement, it is still possible to withstand a large ground reaction force in the landing buffer stage. It may be due to the fact that in order to achieve the technical requirements of stability at the moment of landing, the athletes have almost completed the action of separating the legs and walking before landing in the state of having a large falling distance and falling speed of the center of gravity, which reduces the buffering effect of centrifugal contraction of the lower limbs after landing.

(3) In order to complete the "324C+1D" movement, on the one hand, the trunk rotation speed will be accelerated in the air stage, especially the trunk rotation speed after the stroke. In this state, the athlete may delay the leg splitting time and maintain the high rotational speed in the air for a longer time in order to complete a larger rotation degree, thus causing the trunk rotation speed at the time of landing to be too fast; In addition, if the rotation Angle completed in the air stage is insufficient, it will also be manifested as a phenomenon such as excessive torsion Angle of the shoulders and feet at the moment of landing. Accompanied by this phenomenon, the left external oblique muscle is activated almost simultaneously with the lower limb extensor muscle in the "324C+1D" movement, and the activation time is equal to or slightly larger than the activation time of the lower limb extensor muscle. This indicates that the "324C+1D" movement still needs to activate the trunk rotator muscle group to complete the subsequent trunk corner after landing.

(4) From the perspective of the knee fan Angle and the EMG characteristics of the femoris rects muscle in the landing stage, the athletes' left knee joint takes on a greater cushioning task than the right knee joint in the landing cushioning stage. In particular, high-level athletes in the landing cushioning stage tend to cushion the increased pressure caused by the difficulty step by increasing the left knee fan Angle and the strength of the extensor muscle group. However, if the vertical height of the center of gravity at the moment of landing is too low, it will lead to the lower limb buffering to the squatting state, which will affect the quality of the movement at the landing stage, and it is easy to form a horse step with the center of gravity too low.

2.4 The summary of the main technical characteristics to "324C+1D" movement complete by first-level athletes

(1) The running speed of the "324C+1D" movement has little effect on the completion of the movement; The lifting Angle of the center of gravity at the time of take-off is close to 90°. In the take-off stage, the twisting Angle of shoulders and hips should be appropriately increased, the swinging arm speed should be accelerated, the twisting Angle of shoulders and feet at the moment of departure should be increased, the squatting speed of the center of gravity in the vertical direction should be accelerated, the jumping time of squat and push and stretch should be shortened, and the vertical reaction force of the ground should be increased. The medial head of the gastrocnemius muscle of the left leg and the rectus femoris muscle of the right leg should play the main role of push and stretch. It is beneficial for athletes to improve

the strength of vertical spine muscle by increasing the strength of external oblique muscle and other trunk rotators.

(2) Increase the vertical speed of the center of gravity before striking, increase the vertical moving distance between the center of gravity lifting stage and the center of gravity falling stage, extend the air holding time, accelerate the swing speed of the right leg, move the moment of striking forward to the rapid rising stage of the center of gravity lifting as much as possible, accelerate the rotational angular speed of the shoulder axis in the airborne stage, increase the rotational angular speed of the shoulder axis after striking, and increase the strength of the muscle group of the right leg pressing down. Improving the strength of the vertical spine muscle, the active muscle group of the right leg abduction and the active muscle group of the right turn of the trunk are conducive to the completion of the "324C+1D" movement.

(3) In the cushioning stage of the athlete, the left knee joint assumes a greater cushioning task than the right knee joint, and improving the leg strength, especially the strength of the left leg, is conducive to improving the stability of the athlete in completing the movement.

3. Comparative analysis of the technical characteristics of difficult movements "324C+1D"completed by national athletes and first-level athletes

In order to facilitate the comparative analysis of the technical characteristics of the "324C+1D" movement completed by national athletes and first-class athletes, the 3 national athletes and 3 first-class athletes are divided into two groups, the group of national carriers is "N", and the group of first-class athletes is "F".

3.1 Comparative analysis of technical characteristics of run-up and take-off stages

The take-off requirement of the difficult action "324C+1D" is to take off with both feet and complete the run-up within 4 steps, so the run-up speed requirement of this action is not high, and the time characteristics of the run-up stage, the characteristics of the center of gravity movement speed, the swing arm speed and other characteristics have a very small impact on the completion of the movement, which can be ignored. Therefore, the time characteristics, center of gravity movement characteristics and swing arm speed characteristics of the run-up stage were not analyzed in this study.

3.1.1 Comparative analysis of time characteristics

Table 54 Time for take-off stage (s)

Action stage	Group	$\overline{X} \pm S$	P
Jump squat	N	0. 19±0. 02	0. 51
	F	0. 17±0. 04	
Jump and push	N	0. 21±0. 03	0. 10
	F	0. 25±0. 04	
Take off	N	0. 40±0. 02	0. 67
	F	0. 42±0. 08	

Judging from the total time taken by athletes to complete the take-off stage of "324C+1D" movement (see Table 54), the average time taken by national athletes is 0.40s, that by first-class athletes is 0.42s, and the P-value is 0.67. There is no significant difference in the take-off time between national athletes and first-class athletes.

According to the time taken by athletes to complete the squat stage of "324C+1D" movement, the average time taken by national athletes to complete the squat is 0.19s, and the average time taken by first-class athletes to complete the squat is 0.17s, and the P value is 0.51. There is no significant difference in the time taken by national athletes and first-class athletes to complete the squat stage.

According to the time taken by athletes to complete the "324C+1D" movement, the average time taken by national athletes to complete the "324C+1D" movement is 0.21s, and the average time taken by first-class athletes to complete the jump and squat is 0.25s, and the P value is 0.10. There is no significant difference in the time taken by national athletes and first-class athletes to complete the jump and push and stretch.

3.1.2 Comparative analysis of link motion features

3.1.2.1 Comparative analysis of peak velocity characteristics of swing arm

Table 55 The Peak value of swing arm speed during takeoff (m/s)

Joint	Group	$\overline{X} \pm S$	P
Left arm	N	11. 88±1. 48	0. 97
	F	11. 92±1. 16	
Right arm	N	11. 18±0. 76	0. 23
	F	10. 63±0. 34	

From the perspective of the peak swinging arm speed of athletes completing the take-off stage of "324C+1D" movement (see Table 55), the average value of the peak swinging arm speed of national athletes is 11.88m/s, and that of first-level athletes is 11.92m/s, with a P value of 0.97. There is no significant difference in the peak speed of the left wrist swing arm between the national athletes and the first level athletes in the take-off stage of the "324C+1D" movement.

The average value of the peak speed of the right wrist swing arm of home-level athletes is 11.18m/s, and the average value of the peak speed of the right wrist swing arm of first-level athletes is 10.63m/s, and the P value is 0.23. There is no significant difference in the peak speed of the right wrist swing arm of national-level athletes and first-level athletes when they complete the take-off stage of "324C+1D" movement.

3.1.2.2 Comparative analysis of peak characteristics of shoulder-hip torsion Angle

Table 56 Peak shoulder-hip torsion Angle in run-up start stage (°)

Action stage	Group	$\overline{X} \pm S$	P
run-up	N	51. 08±10. 39	0. 69
	F	55. 14±8. 63	
Take-off phase	N	63. 65±8. 81	0. 05
	F	78. 14±8. 33	

According to the peak value of shoulder-hip torsion Angle of athletes in the run-up stage of "324C+1D" movement (see Table 56), the average value of the peak value of shoulder-hip torsion Angle of national athletes in the run-up stage is 51.08°, and that of first-class athletes in the run-up stage is 55.14°, and the P value is 0.69. There was no significant difference in the peak value of shoulder-hip torsion Angle between national athletes and first level athletes during the run-up of "324C+1D".

According to the peak value of shoulder-hip torsion Angle of athletes in the take-off stage of "324C+1D" movement (see Table 56), the average value of the peak value of shoulder-hip torsion Angle of national athletes in the take-off stage is 63.65°, and that of first-class athletes in the take-off stage is 78.14°, and the P value is 0.05. There was no significant difference in the peak value of shoulder-hip torsion Angle between the national athletes and the first level athletes in the take-off stage of "324C+1D" movement.

3.1.2.3 Comparative analysis of shoulder and foot torsion Angle characteristics

Table 57 Shoulder and foot torsion Angleat take-off stage (°)

Action moment	Group	$\overline{X} \pm S$	P
Take-off stage off the ground time	N	90. 60±8. 62	0. 91
	F	92. 38±16. 83	

From the perspective of the shoulder and foot torsion Angle of athletes completing the "324C+1D" movement in the take-off stage (see Table 57), the average value of the shoulder and foot torsion Angle of national athletes in the take-off stage is 90.60°, and that of first-class athletes in the take-off stage is 92.38°, and the P value is 0.91. There is no significant difference between the shoulder-foot torsion Angle of the national athletes and the first-level athletes in the take-off stage of "324C+1D" movement.

3.1.2.4 Comparative analysis of ankle, knee and hip joint Angle characteristics during take-off, push and stretch

3.1.2.4.1 Comparative analysis of the Angle of the left and right ankle joints at the time of takeoff and squat and the time of departure from the ground

Table 58 Ankle joint Angle during take-off, push and stretch (°)

Joint	Action moment	Group	$\overline{X} \pm S$	P
Left ankle	Jump squat	N	93. 08±14. 43	0. 31
		F	55. 91±35. 73	
	Time off ground	N	116. 97±33. 75	0. 15
		F	74. 19±65. 71	
Right ankle	Jump squat	N	94. 52±5. 48	0. 20
		F	84. 81±11. 24	
	Time off ground	N	130. 64±22. 51	0. 90
		F	132. 65±1. 77	

From athletes "324 C + 1 D" finish jump stretching in phase jump crouch down moments of left ankle Angle (see table 58), national athletes jump stretching in phase jump crouch down moments left ankle average Angle is 93.08 °, level athletes jump stretching in phase jump crouch down moments left ankle average Angle is 55.91 °, The P value was 0.31, and there was no significant difference in the Angle of left ankle between the national athletes and the first-level athletes when they completed the "324C+1D" take-off, push-off and extension stage.

From the perspective of the left ankle at the time off the ground when the athletes complete the "324C+1D" movement take-off, push and stretch stage (see Table 58), the average Angle of the left ankle at the time off the ground during the national athletes' take-off, push and stretch stage is 116.97°, and the average Angle of the left ankle at the time off the ground during the first-level athletes' take-off, push and stretch stage is 74.19°, P value is 0.15. There was no significant difference in the Angle of left ankle between the national athletes and the first level athletes when they completed the "324C+1D" take-off, push and extension stage.

From the perspective of the right ankle at the time when the athlete completed the "324C+1D" movement take-off, push, and stretch stage take-off and squat moment (see Table 58), the average Angle of the right ankle at the time of take-off, push, and stretch stage take-off and squat moment of the national athletes is 94.52°, and the average Angle of the right ankle at the time of take-off, push, and stretch stage of the first-level athletes is 84.81°. The P value was 0.20, and there was no significant difference in the right ankle Angle between the national athletes and the first-level athletes when they completed the "324C+1D" take-off, push-off and extension stage.

From the perspective of the right ankle at the time off the ground when the athletes complete the "324C+1D" movement take-off, push and stretch stage (see Table 58), the average right ankle Angle at the time off the ground of the national athletes is 130.64°, and the average right ankle Angle at the time off the ground of the first-level athletes is 132.65°, and the P value is 0.90. There was no significant difference in the Angle of right ankle joint between national athletes and first level athletes when they completed the "324C+1D" take-off, push and stretch stage.

3.1.2.4.2 Comparative analysis of the angles of the two knee joints at the moment of takeoff and squat and the moment of departure from the ground

Table 59 Knee joint Angle during take-off, push and extension (°)

Joint	Action moment	Group	$\overline{X} \pm S$	P
Left knee	Jump squat	N	103. 30±7. 07	0. 81
		F	101. 20±26. 48	
	Time off ground	N	140. 93±34. 71	0. 49
		F	159. 82±18. 34	
Right knee	Jump squat	N	84. 86±6. 71	0. 86
		F	81. 61±28. 70	
	Time off ground	N	152. 39±31. 54	0. 58
		F	165. 90±11. 94	

From athletes "324 C + 1 D" finish jump stretching in phase jump crouch down moments left knee joint Angle (see table 59), national athletes jump stretching in phase jump crouch down time average of 103.30 °, left knee joint Angle level athletes jump stretching in phase jump crouch down time average of 101.20 ° left knee joint Angle, The P value is 0.81, and there is no significant difference in the

Angle of left knee joint between the national athletes and the first-level athletes when they complete the "324C+1D" take-off, push-off and extension stage.

From the perspective of left knee joint at the time off the ground when athletes complete the "324C+1D" movement take-off, push and stretch stage (see Table 59), the average Angle of left knee joint at the time off the ground for national athletes is 140.93°; the average Angle of left knee joint at the time off the ground for first-level athletes is 159.82°, and the P value is 0.49. There is no significant difference in the Angle of left knee joint between the national athletes and the first level athletes when they complete the "324C+1D" take-off, push and extension stage.

From the perspective of the right knee joint at the time when the athlete completed the "324C+1D" movement take-off, push-off and extension stage take-off and squat (see Table 59), the average Angle of the right knee joint at the time of take-off, push-off and extension stage of national athletes is 84.86°, and the average Angle of the right knee joint at the time of take-off, push-off and extension stage of first-level athletes is 81.61°. The P value was 0.86, and there was no significant difference in the right knee Angle between the national athletes and the first-level athletes when they completed the "324C+1D" take-off, push-off and extension stage.

From the perspective of the right knee joint at the time off the ground when the athletes complete the "324C+1D" movement take-off, push and extend stage (see Table 59), the average Angle of the right knee joint at the time off the ground of the national athletes is 152.39°, and the average Angle of the right knee joint at the time off the ground of the first-level athletes is 165.90°, and the P value is 0.58. There was no significant difference in the right knee Angle between the national athletes and the first level athletes when they completed the "324C+1D" take-off and extension stage.

3.1.2.4.3 Comparative analysis of the joint angles of left and right hip joints at the squat moment and off the ground moment during takeoff

Table 60 Hip joint Angle during take-off and extension (°)

Joint	Action moment	Group	$\overline{X} \pm S$	P
Left hip	Jump squat	N	115. 35±21. 47	0. 96
		F	114. 57±19. 39	
	Time off	N	138. 81±27. 71	0. 40

	ground	F	158. 49±10. 45	
Right hip	Jump squat	N	73. 90±13. 96	0. 63
		F	68. 62±18. 63	
	Time off ground	N	143. 69±24. 74	0. 58
		F	155. 71±7. 80	

From athletes "324C + 1 D" finish jump stretching in phase jump crouch down moments left hip Angle (see table 60), national athletes jump stretching in phase jump crouch down time average Angle is 115.35 °, the left hip level athletes jump stretching phase jump crouch down average moments left hip Angle is 114.57 °, The P value was 0.96, and there was no significant difference in the Angle of left hip joint between the national athletes and the first-level athletes when they completed the "324C+1D" take-off, push-off and extension stage.

From the Angle of left hip joint when athletes complete the "324C+1D" movement in the take-off, push and stretch stage off the ground (see Table 60), the average Angle of left ankle joint at the moment off the ground during the take-off, push and stretch stage of national athletes is 138.81°, and the average Angle of left hip joint at the moment off the ground during the take-off, push and stretch stage of first-level athletes is 158.49°, P value is 0.40. There was no significant difference in the Angle of left hip joint between the national athletes and the first level athletes when they completed the "324C+1D" take-off and extension stage.

From the perspective of the right hip joint at the takeoff and squat moment when athletes complete the "324C+1D" movement (see Table 60), the average right hip Angle at the takeoff and squat moment of the national athletes is 73.90°, and the average right hip Angle at the takeoff and squat moment of the first-level athletes is 68.62°. The P value was 0.63, and there was no significant difference in right hip Angle between national athletes and first-level athletes when they completed the "324C+1D" take-off, push-off and extension stage.

From the perspective of the right hip joint when athletes complete the "324C+1D" movement in the take-off, push and stretch stage off the ground (see Table 60), the average Angle of the right hip joint at the take-off, push and stretch stage off the ground of national athletes is 143.69°, and the average Angle of the right hip joint at the take-off, push and stretch stage of first-level athletes is 155.71°, P value is 0.58. There was no significant difference in the right hip Angle between the national athletes and the first level athletes when they completed the "324C+1D" take-off and extension stage.

3.1.3 Comparative analysis of gravity center movement characteristics

3.1.3.1 Comparative analysis of center of gravity speed characteristics in the run-up direction

Table 61 Center of Gravity Speed in the run-up direction (m/s)

Action moment	Group	$\overline{X} \pm S$	P
Run-up (peak value)	N	2. 59±0. 55	0. 30
	F	2. 99±0. 07	
End of run-up	N	2. 38±0. 70	0. 74
	F	2. 30±0. 36	
Time off ground	N	0. 80±0. 27	0. 77
	F	0. 72±0. 22	

According to the peak value of the center of gravity speed in the run-up direction of athletes completing the "324C+1D" movement (see Table 61), the average value of the peak value of the center of gravity speed in the run-up direction of national athletes is 2.55m /s, and the average value of the peak value of the center of gravity speed in the run-up direction of first-level athletes is 2.99m /s, and the P value is 0.30. There is no significant difference between national athletes and first-class athletes in the peak speed of the center of gravity in the run-up direction of the "324C+1D" movement.

From the point of view of the center of gravity speed at the end of the run-up for athletes completing the "324C+1D" movement (see Table 61), the average center of gravity speed at the end of the run-up for national athletes is 2.38m /s, and the average center of gravity speed at the end of the run-up for first-class athletes is 2.30m /s, and the P value is 0.74. There is no significant difference in the center of gravity speed between the national athletes and the first level athletes at the end of the run-up period of "324C+1D".

From the point of view of the center of gravity velocity at the time of lifting off the ground when the athletes complete the run-up stage of "324C+1D" movement (see Table 61), the average center of gravity velocity at the time of lifting off the ground of the national athletes is 0.80m /s, and the average center of gravity velocity at the time of lifting off the ground of the first-level athletes is 0.72m /s, and the P value is 0.77. There is no significant difference in the center of gravity velocity between the national athletes and the first level athletes at the time of departure from the ground during the run-up of "324C+1D".

3.1.3.2 Comparative analysis of peak characteristics of vertical velocity of gravity center

Table 62 Peak vertical velocity of the center of gravity during takeoff (m/s)

Action moment	Group	$\overline{X} \pm S$	P
Jump squat	N	−1. 69±0. 21	0. 17
	F	−2. 30±0. 49	
Jump and push	N	2. 87±0. 42	0. 77
	F	2. 99±0. 22	

According to the peak value of vertical velocity of the center of gravity at the time of takeoff and squat of athletes completing the "324C+1D" movement (see Table 62), the average value of the peak value of vertical velocity of the center of gravity at the time of takeoff and squat of national athletes is -1.69m /s, and that of first-level athletes at the time of takeoff and squat is -2.30m /s. The P value is 0.17, and there is no significant difference between national athletes and first-level athletes in the peak vertical speed of the center of gravity at the time of takeoff and squat of the "324C+1D" movement.

According to the peak value of the vertical speed of the center of gravity at the time of take-off, push and stretch of athletes completing the "324C+1D" movement (see Table 62), the average value of the peak value of the vertical speed of the center of gravity at the moment of take-off, push and stretch of national athletes is 2.87m /s, and the average value of the peak value of the vertical speed of the center of gravity at the moment of take-off, push and stretch of first-level athletes is 2.99m /s. The P value is 0.77, and there is no significant difference between national athletes and first level athletes in the peak vertical speed of the center of gravity at the time of take-off and push out of the "324C+1D" movement.

3.1.3.3 Comparative analysis of vertical movement distance of center of gravity

Table 63 Vertical movement distance of Center of gravity during take-off (m)

Action moment	Group	$\overline{X} \pm S$	P
Jump squat	N	0. 26±0. 06	0. 23
	F	0. 33±0. 05	
Jump and push	N	0. 28±0. 14	0. 71
	F	0. 36±0. 18	

From the perspective of the vertical movement distance of the center of gravity at the time of takeoff and squat of athletes completing the "324C+1D" movement (see Table 63), the average vertical movement distance of the center of gravity at the time of takeoff and squat of national athletes is 0.26m, and the average vertical movement distance of the center of gravity at the time of takeoff and squat of first-level athletes is 0.33m, and the P value is 0.23. There is no significant difference in the vertical movement distance of the center of gravity between the national athletes and the first level athletes when they complete the "324C+1D" movement.

From the perspective of the vertical movement distance of the center of gravity at the take-off, push and stretch moment of the athletes completing the "324C+1D" movement (see Table 63), the average vertical movement distance of the center of gravity at the take-off, push and stretch moment of the national athletes is 0.28m, and the average vertical movement distance of the center of gravity at the take-off, push and stretch moment of the first-level athletes is 0.36m, and the P value is 0.71. There is no significant difference in the vertical movement distance of the center of gravity between the national athletes and the first level athletes in the take-off stage of "324C+1D" movement.

3.1.3.4 Comparative analysis of center of gravity lifting Angle characteristics at the time of liftoff

Table 64 Center of gravity lifting Angleat take-off stage (°)

Group	$\overline{X} \pm S$	P
N	72. 69±6. 64	0. 52
F	70. 18±2. 16	

From the Angle of center of gravity lifting at the time of take-off of athletes completing "324C+1D" movement (see Table 64), the average Angle of center of gravity lifting at the time of take-off of national athletes is 72.69°, and the average Angle of center of gravity lifting at the time of take-off of first-level athletes is 70.18°, and the P value is 0.52. There is no significant difference between national athletes and first level athletes in the lifting Angle of the center of gravity at the time of take-off of the "324C+1D" movement.

3.1.4 Comparative analysis of peak characteristics of ground vertical reaction force

Table 65 Peak value of ground vertical reaction force during take-off and extension (BW)

Group	$\overline{X} \pm S$	P
N	38. 63±3. 73	0. 08
F	32. 24±0. 74	

According to the peak value of the ground vertical reaction force of athletes completing the "324C+1D" movement in the take-off, push and stretch stage (see Table 65), the average value of the ground vertical reaction force peak value of national athletes in the take-off, push and stretch stage is 38.63BW, and that of first-class athletes in the take-off, push and stretch stage is 32.24BW. With a P value of 0.08, there is no significant difference in the peak value of ground vertical reaction force between the national athletes and the first-level athletes in the take-off and push phase of "324C+1D" movement.

3.1.5 Comparative analysis of myoelectric features

According to the test results, not all of the 12 muscles selected for testing in this movement stage participated in the work, and only part of the muscles showed activation state. In this study, only the muscles showing activation state were selected for muscle activation sequence (activation time) analysis and integrated electromyography analysis.

3.1.5.1 Comparative analysis of activation sequence (activation time) of relevant muscles in the take-off stage

From the activation sequence of muscles related to the take-off stage of national athletes completing the "324C+1D" movement (see Figure 28) and the activation sequence of muscles related to the take-off stage of first-level athletes completing the "324C+1D" movement (see Figure 29), The order of muscle activation in the take-off stage of national athletes and the order of muscle activation in the take-off stage of first-level athletes showed a high consistency. The relevant muscle groups selected in this study did not reach the activated state at the beginning of the jump. With the continuous decline of the center of gravity, the right thigh rectus femoris muscle, the left thigh rectus femoris muscle, the right abdominal external oblique muscle and the left abdominal external oblique muscle were activated successively to regulate the height of the center of gravity and body posture. The medial head of gastrocnemius muscle of right leg and medial head of gastrocnemius muscle of left leg were activated relatively late. The activation time of the left external oblique muscle was the latest, but the activation time was until the end of the jump phase.

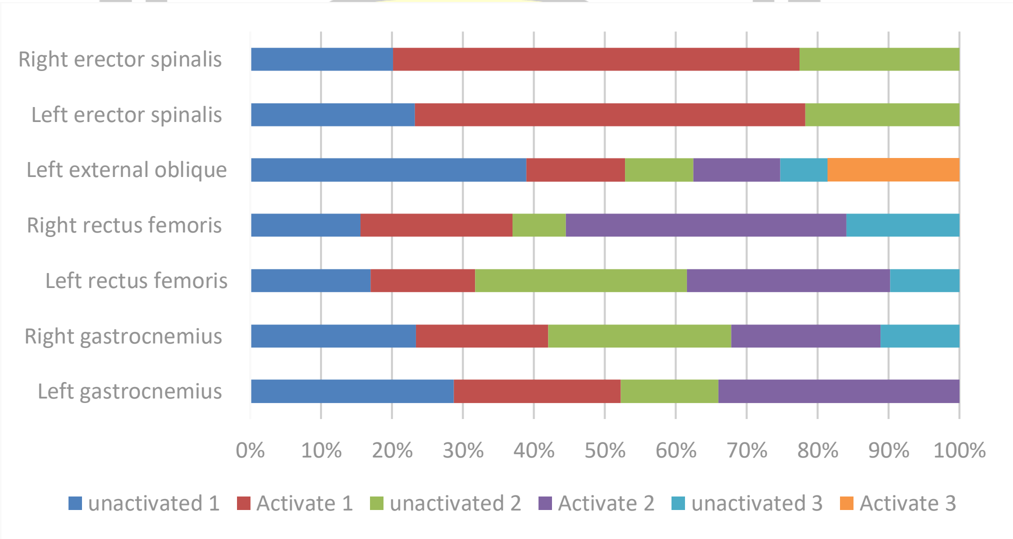

Figure 28 Activation sequence of muscles related to the take-off stage of national athletes

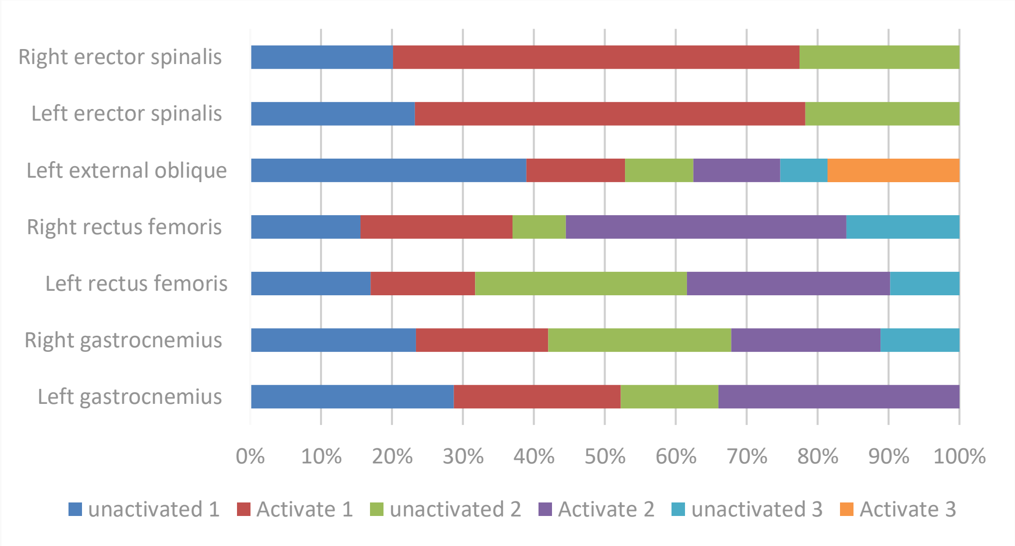

Figure 29 Activation sequence of muscle related to the take-off stage of first level athletes

3.1.5.2 Comparative analysis of integrated EMG values of relevant muscles in the take-off stage

Table 66 Integrated electromyography value of relevant muscles during the take-off stage (μVs)

Muscle	Group	$\overline{X} \pm S$	P
Left gastrocnemius	N	2274. 47±5. 25	0. 93
	F	2274. 86±11. 81	
Right gastrocnemius	N	1331. 04±29. 97	0. 62
	F	1333. 54±37. 38	
Left rectus femoris	N	2456. 17±17. 96	0. 72
	F	2458. 33±25. 68	
Right rectus femoris	N	2848. 90±25. 24	0. 75
	F	2851. 09±35. 15	
Left external oblique	N	786. 89±9. 67	0. 92
	F	787. 20±14. 22	
Left erector spinalis	N	1964. 95±28. 61	0. 99
	F	1964. 92±33. 83	
Right erector spinalis	N	2174. 35±36. 54	0. 83
	F	2175. 37±43. 39	

According to the integrated EMG values of the gastrocnemius of the left leg and the gastrocnemius of the right leg after the athletes complete the "324C+1D" movement at the take-off stage (see Table 66), the average value of the integrated

EMG values of the gastrocnemius of the left leg of the national athletes at the take-off stage is 2274.47μVs, and the average value of the integrated EMG values of the left leg of the first-level athletes at the take-off stage is 2274.86μVs. The P value is 0.93, and there is no significant difference between the national athletes and the first-level athletes in the left leg gastrocnemius integrated EMG value after the "324C+1D" movement take-off stage. The average value of the integrated EMG of the gastrocnemius of the right leg of the national athletes is 1331.04μVs, and the average value of the integrated EMG of the gastrocnemius of the right leg of the first-level athletes is 1333.54μVs, and the P value is 0.62. There is no significant difference between the national athletes and the first level athletes in the integral myoelectric value of the gastrocnemius muscle of the right leg in the take-off stage of "324C+1D" movement.

From the point of view of the integrated EMG value of the left thigh rectus femoris and the right thigh rectus femoris in the take-off stage of the athletes' "324C+1D" movement (see Table 66), the average value of the integrated EMG value of the left thigh rectus femoris in the take-off stage of the national athletes is 2456.17 μVs, and the average value of the integrated EMG value of the left thigh rectus femoris in the take-off stage of the first-level athletes is 2458.33μVs. The P value is 0.72, and there is no significant difference in the integrated EMG value of the left thigh rectus muscle between the national athletes and the first-level athletes in the take-off stage of "324C+1D" movement. The average value of the integrated EMG of the right rectus femoris muscle of the national athletes is 2848.90μVs, and the average value of the integrated EMG of the right rectus femoris of the first-level athletes is 2851.09μVs, and the P value is 0.75. There is no significant difference between the national athletes and the first level athletes in the integrated EMG value of the right thigh rectus muscle in the take-off stage of "324C+1D" movement.

From the point of view of the integral myoelectric value of the left external oblique muscle of the athlete completing the "324C+1D" movement in the take-off stage (see Table 66), the average value of the integral myoelectric value of the left external oblique muscle of the national athlete in the take-off stage is 786.89μVs, and the average value of the integral myoelectric value of the left external oblique muscle of the first-level athlete in the take-off stage is 787.20μVs. The P value was 0.92, and there was no significant difference in the integral EMG value of the left external oblique muscle of the national athletes and the first-level athletes in the take-off stage of "324C+1D" movement.

According to the integrated EMG values of the left and right vertical spine muscles of athletes completing the "324C+1D" movement in the take-off stage (see Table 66), the average value of the left vertical spine muscles in the take-off stage of national athletes is 1964.95μVs, and the average value of the left vertical spine muscles in the take-off stage of first-level athletes is 1964.92μVs. The P value is 0.99, and there is no significant difference between the national athletes and the first-level athletes in the integrated EMG value of the left vertical spine muscle during the take-off stage of "324C+1D" movement. The average value of the integrated myoelectric value of the right vertical spine muscle in the take-off stage of national athletes is 2174.35μVs, and the average value of the integrated myoelectric value of the right vertical spine muscle in the take-off stage of first-class athletes is 2175.37μVs, and the P value is 0.83. There is no significant difference between the national athletes and the first level athletes in the integration of the right vertical spinal muscle in the jumping stage of "324C+1D" movement.

3.1.6 Comparative analysis and summary of technical characteristics of run-up and take-off stages

(1) There is no significant difference between national athletes and first-level athletes in the time taken to complete the "324C+1D" movement take-off and squat stage, take-off and push and stretch stage, and the total time taken in the take-off stage.

(2) There is no significant difference between the peak swinging arm speed of the left arm and the right arm of the national athletes and the first-level athletes who complete the "324C+1D" movement take-off stage.

(3) There was no significant difference in the peak value of shoulder-hip torsion Angle between the national athletes and the first-level athletes who completed the "324C+1D" movement in the run-up stage and the take-off stage.

(4) There is no significant difference between the shoulder-foot torsion Angle of the national athletes and the first-level athletes in the take-off stage of the "324C+1D" movement.

(5) There is no significant difference in the Angle of ankle joints, knee joints and hip joints between the national athletes and the first-level athletes when they complete the "324C+1D" take-off, push-off and extension stage.

(6) There is no significant difference between the peak value of the center of gravity speed in the run-up direction, the center of gravity speed at the end of the run-up and the center of gravity speed at the time of departure from the ground during the run-up between the national athletes and the first level athletes after completing the "324C+1D" movement.

(7) There is no significant difference between national athletes and first-level athletes in the peak vertical speed of the center of gravity at the takeoff squat moment and the takeoff push and stretch moment of the "324C+1D" movement.

(8) There is no significant difference in the vertical movement distance of the center of gravity between the national athletes and the first-level athletes when they complete the "324C+1D" movement.

(9) There is no significant difference in the lifting Angle of the center of gravity when the national athletes and the first-level athletes finish the "324C+1D" movement take-off stage.

(10) There is no significant difference in the peak value of the ground vertical reaction force between the national athletes and the first-level athletes who complete the "324C+1D" take-off and push stage.

(11) The muscle activation sequence of the "324C+1D" movement of the national athletes and the first-level athletes showed a high consistency, and the difference of the integrated electromyography value of the relevant muscles was not significant.

To sum up, there is no significant difference between the biomechanical characteristics of national athletes and first-level athletes in the run-up and take-off stages of "324C+1D" movements.

3.2 Comparative analysis of technical characteristics in the vacating stage

3.2.1 Comparative analysis of time characteristics

Table 67 Duration of the vacating phase (s)

Action stage	Group	$\overline{X} \pm S$	P
Off the ground to beat	N	0.16±0.02	0.06
	F	0.18±0.01	
Off the ground to beat	N	0.52±0.03	0.68
	F	0.50±0.04	
The whole flight phase	N	0.68±0.02	0.93
	F	0.68±0.04	

Judging from the total time taken by athletes to complete the airborne phase of "324C+1D" movement (see Table 67), the average time taken by national athletes is 0.68s, and that by first-class athletes is also 0.68s, with a P value of 0.93. There is no significant difference in the airborne phase time between national athletes and first-class athletes.

From the perspective of the time taken by athletes to complete the ground to beat stage of "324C+1D" movement, the average time taken by national athletes to complete the ground to beat stage is 0.16s, and the average time taken by first-class athletes to complete the ground to beat stage is 0.18s, and the P value is 0.06. There is no significant difference in the time taken by national athletes and first-class athletes to complete the ground to beat stage.

From the perspective of the time taken by athletes to complete the "324C+1D" movement hitting to the landing stage, the average time taken by national athletes to complete the hitting to the landing stage is 0.52s, and the average time taken by first-class athletes to complete the hitting to the landing stage is 0.50s, and the P value is 0.68. There is no significant difference between national athletes and first-class athletes in the hitting to the landing stage.

3.2.2 Comparative analysis of link motion features

3.2.2.1 Comparative analysis of right leg swing speed characteristics

Table 68 Right leg swing Speed during the airborne phase (m/s)

Action stage	Group	$\overline{X} \pm S$	P
Pre-beat (Peak value)	N	11.54±0.23	0.82
	F	11.74±1.28	
Tap time	N	11.05±0.85	0.28
	F	8.53±3.01	
After beat (Peak value)	N	10.96±1.03	0.20
	F	9.36±1.59	

According to the peak value of the right leg swing speed before the athlete completes the "324C+1D" movement in the air stage of tapping (see Table 68), the average value of the right leg swing speed of national athletes is 11.54m /s, and that of first-level athletes is 11.74m /s, with a P value of 0.82. There is no significant difference in the peak value of right leg swing speed between the national athletes and the first level athletes in the air stage.

From the point of view of the swing speed of the right leg at the moment when the athlete completes the "324C+1D" movement in the air stage of striking (see Table 68), the average swing speed of the right leg of the national athlete is 11.05m /s, and the average swing speed of the right leg of the first-level athlete is 8.53m /s, and the P value is 0.28. There is no significant difference in the swing speed of the right leg between the national athletes and the first level athletes.

From the peak value of the right leg swing speed after the athlete completed the "324C+1D" movement in the air stage of the stroke (see Table 68), the average value of the right leg swing speed of the national athletes is 10.96m /s, and the average value of the right leg swing speed of the first-level athletes is 9.36m /s, P value is 0.20. There is no significant difference in the peak value of right leg swing speed between the national athletes and the first level athletes.

3.2.2.2 Comparative analysis of angular velocity characteristics of shoulder shaft rotation

Table 69 Rotational angular velocity of the shoulder axis in the airborne stage (°/s)

Action stage	Group	$\overline{X} \pm S$	P
Tap time	N	609. 97±96. 00	0. 56
	F	573. 08±124. 09	
After beat (Peak value)	N	2000. 66±405. 45	0. 74
	F	1933. 28±130. 96	
Landing time	N	705. 70±138. 74	0. 66
	F	647. 31±197. 79	

According to the angular velocity of the shoulder axis at the moment when the athlete completed the "324C+1D" movement in the air stage of the stroke (see Table 69), the average angular velocity of the shoulder axis of the national athlete is 609.97 °/s, and that of the first-level athlete is 573.08 °/s, with a P value of 0.56. There is no significant difference in the angular velocity of the shoulder axis between the national athletes and the first level athletes.

According to the peak angular velocity of the shoulder shaft after the athlete completed the "324C+1D" movement in the air stage of striking (see Table 69), the average value of the peak angular velocity of the shoulder shaft is 2000.66 °/s for national athletes and 1933.28 °/s for first-class athletes, and the P value is 0.74. There is no significant difference in the peak angular velocity of the shoulder axis between the national athletes and the first level athletes.

From the perspective of the angular velocity of the shoulder shaft at the landing moment when the athlete completes the "324C+1D" movement in the air stage (see Table 69), the average peak angular velocity of the national athlete is 705.70 °/s, and that of the first-class athlete is 647.31 °/s, with a P value of 0.66. There is no significant difference in the angular velocity of the shoulder axis between the national athletes and the first level athletes.

3.2.3 Movement characteristics of center of gravity

3.2.3.1 Vertical Velocity Characteristics of center of gravity

Table 70 Vertical Velocity of the Center of gravity in the take-off stage (m/s)

Action moment	Group	$\overline{X} \pm S$	P
Pre-beat (Peak value)	N	2.94±0.21	0.38
	F	2.78±0.05	
Tap time	N	1.60±0.59	0.40
	F	1.32±0.15	

From the peak value of vertical speed of the center of gravity before the athlete completed the "324C+1D" movement in the air stage of striking (see Table 70), the average value of vertical speed of the center of gravity of national athletes is 2.94 m/s, and that of first-class athletes is 2.78 m/s, and the P value is 0.38. There is no significant difference in the vertical speed of the center of gravity before striking between the national athletes and the first level athletes.

From the vertical speed of the center of gravity at the moment when the athlete completed the "324C+1D" movement in the air stage of striking (see Table 70), the average vertical speed of the center of gravity of the national athlete is 1.64m /s, the average vertical speed of the center of gravity of the first-level athlete is 1.32m /s, and the P value is 0.40. There is no significant difference in the vertical speed of the center of gravity between the national athletes and the first level athletes.

3.2.3.2 Vertical height characteristics of the center of gravity at the time of departure and landing

Table 71 Vertical height of the Center of gravity at the time of departure and landing (m)

Action moment	Group	$\overline{X} \pm S$	P
Time off ground	N	1. 07±0. 16	0. 65
	F	1. 14±0. 06	
Landing time	N	0. 97±0. 10	0. 44
	F	0. 88±0. 10	

From the vertical height of the center of gravity at the time when the athlete completed the "324C+1D" movement in the air stage off the ground (see Table 71), the average vertical height of the center of gravity of the national athlete is 1.07m, the average vertical height of the center of gravity of the first-level athlete is 1.14m, and the P value is 0.65. There is no significant difference in the vertical height of the center of gravity at the time of take-off between the national athletes and the first level athletes.

From the vertical height of the center of gravity at the landing moment when the athletes complete the "324C+1D" movement in the air stage (see Table 71), the average vertical height of the center of gravity of the national athletes is 0.97m, the average vertical height of the center of gravity of the first-level athletes is 0.88m, and the P value is 0.44. There is no significant difference in the vertical height of the center of gravity at the landing moment between national athletes and first-class athletes.

3.2.3.3 Comparative analysis of vertical movement distance of center of gravity

Table 72 Vertical movement distance of the Center of gravity in each stage of flight (m)

Moving direction	Group	$\overline{X} \pm S$	P
Center of gravity lifting	N	0. 50±0. 13	0. 39
	F	0. 42±0. 01	
Fall of center of gravity	N	0. 60±0. 15	0. 80
	F	0. 65±0. 19	

From the point of view of the lifting distance of the center of gravity during the "324C+1D" movement in the air stage (see Table 72), the average lifting distance of the center of gravity of the national athletes is 0.50 m, the average lifting distance of the center of gravity of the first-level athletes is 0.42 m, and the P value is 0.39. There is no significant difference in the lifting distance between the national athletes and the first level athletes.

From the point of view of the center of gravity falling distance of athletes in the airborne stage of "324C+1D" movement (see Table 72), the average center of gravity falling distance of national athletes is 0.60m, the average center of gravity falling distance of first-class athletes is 0.65m, and the P value is 0.80. There is no significant difference between the center of gravity fall distance between the national athletes and the first level athletes.

3.2.4 Comparative analysis of EMG features

According to the test results, not all of the 12 muscles selected for testing in this movement stage participated in the work, and only part of the muscles showed activation state. In this study, only the muscles showing activation state were selected for muscle activation sequence (activation time) analysis and integrated electromyography analysis.

3.2.4.1 Comparative analysis of activation sequence (activation time) of relevant muscles in the flight stage

From the activation sequence of muscles related to the air stage of national athletes completing the "324C+1D" movement (see Figure 30) and the activation sequence of muscles related to the air stage of first-level athletes completing the

"324C+1D" movement (see Figure 31), The muscle activation sequence of the national athletes in the air stage showed a high consistency with that of the first-level athletes in the air stage. The left external oblique muscles, the right thigh rectus femoris, and the right thigh gluteus maximus are activated first, indicating that the right leg swings up and out while the left external oblique muscles contract to put the torso in a right-turning position. Second, the right vertical ridge muscle was activated, and the activation time of the left vertical ridge muscle was later than that of the right vertical ridge muscle, indicating that the swing of the right leg may have an impact on the right vertical ridge muscle, causing the right vertical ridge muscle to be activated first. The biceps femoris of the right leg activates later, but stays active longer.

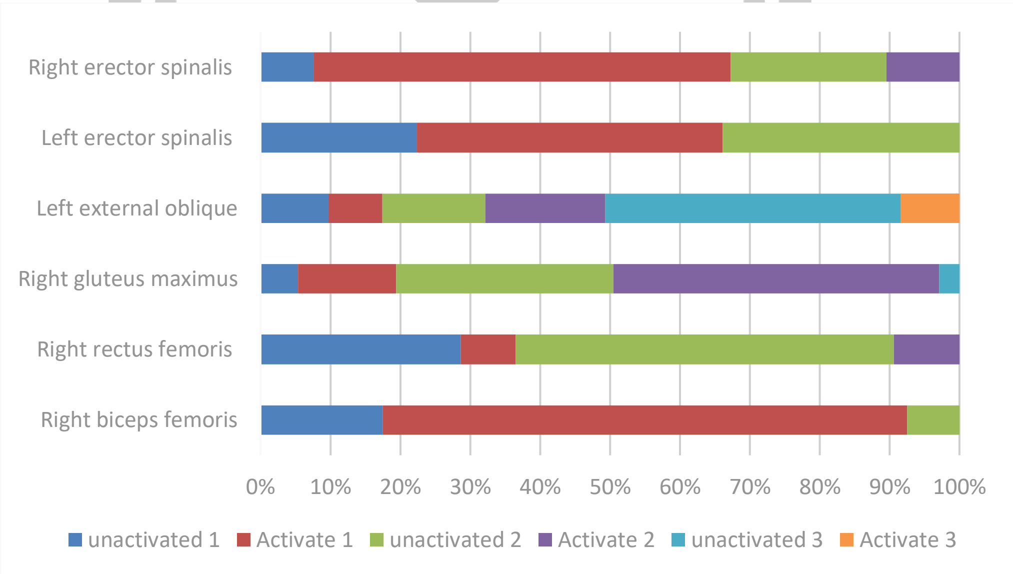

Figure 30 Muscle activation sequence of national athletes in the air stage

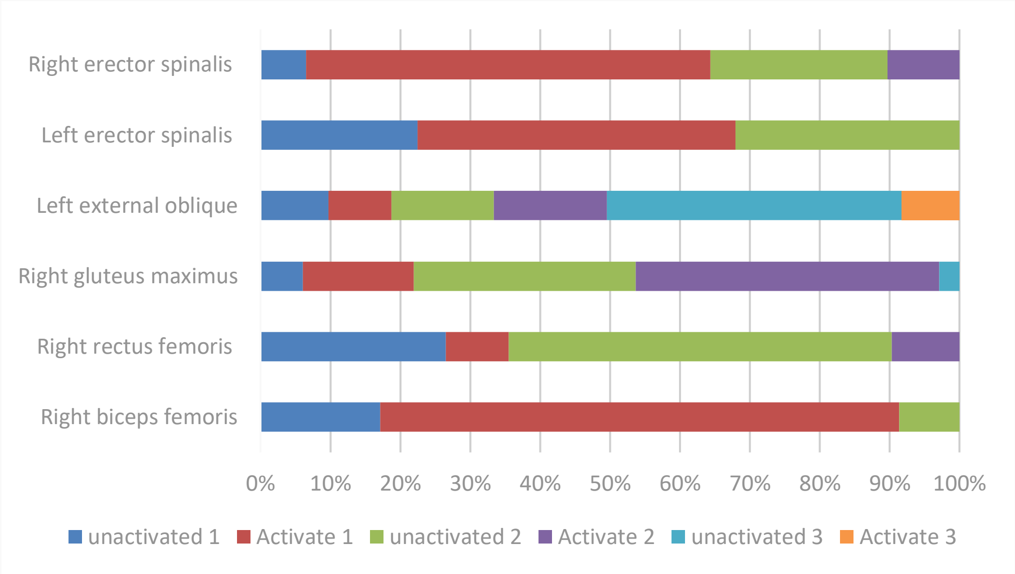

Figure 31 Muscle activation sequence of first level athletes in the air stage

3.2.4.2 Comparative analysis of integrated EMG values of relevant muscles in the vacating stage

Table 73 Integrated electromyography value of relevant muscles during the flight stage (μVs)

Muscle	Group	$\overline{X} \pm S$	P
Right biceps femoris	N	4766. 50±70. 46	0. 72
	F	4760. 20±96. 87	
Right rectus femoris	N	1254. 47±21. 40	0. 72
	F	1269. 34±82. 84	
Right gluteus maximus	N	732. 89±3. 67	0. 44
	F	764. 66±61. 43	
Left external oblique	N	800. 63±14. 30	0. 45
	F	834. 86±78. 59	
Left erector spinalis	N	2168. 38±5. 20	0. 13
	F	2218. 24±39. 80	
Right erector spinalis	N	2221. 86±17. 82	0. 17
	F	2276. 04±61. 89	

From the point of view of the integrated EMG value of the right biceps femoris of the athlete's right leg in the air stage of the "324C+1D" movement (see Table 73), the average value of the integrated EMG value of the right biceps femoris of the national athlete in the air stage is 2766.50μVs, and the average value of the integrated EMG value of the right biceps femoris of the first-level athlete in the air stage is 4760.20μVs. The P value was 0.72, and there was no significant difference in the integrated EMG value of the biceps femoris of the right leg between the national athletes and the first-level athletes after the "324C+1D" movement in the air stage.

From the point of view of the integrated EMG value of the right rectus femoris muscle of the athlete's right leg in the air stage of the "324C+1D" movement (see Table 73), the average value of the integrated EMG value of the right rectus femoris muscle of the national athlete in the air stage is 1254.47μVs, and the average value of the integrated EMG value of the right rectus femoris of the first-level athlete in the air stage is 1269.34μVs. The P value is 0.72, and there is no significant difference in the integrated EMG value of the right thigh rectus muscle between the national athletes and the first-level athletes after the "324C+1D" movement.

From the point of view of the integrated myoelectric value of the right gluteus maximus in the air stage of athletes completing "324C+1D" movement (see Table 73), the average value of the integrated myoelectric value of the right gluteus maximus in the air stage of national athletes is 732.89μVs, and the average value of the integrated myoelectric value of the right gluteus maximus in the air stage of first-class athletes is 764.66μVs, and the P value is 0.44. There was no significant difference in the integrated myoelectric value of right gluteus maximus between the national athletes and the first level athletes who completed the "324C+1D" movement.

From the point of view of the integral EMG value of the left external oblique muscle of the athlete completing the "324C+1D" movement in the air stage (see Table 73), the average value of the integral EMG value of the left external oblique muscle of the national athlete in the air stage is 800.63μVs, and the average value of the integral EMG value of the left external oblique muscle of the first-level athlete in the air stage is 834.86μVs. The P value was 0.45, and there was no significant difference in the integrated EMG value of the left external oblique muscle of the abdomen between the national athletes and the first-level athletes after completing the "324C+1D" movement.

From the point of view of the integrated EMG values of the left and right vertical spine muscles of athletes completing the "324C+1D" movement in the air stage (see Table 73), the average value of the left vertical spine muscles in the air stage of national athletes is 2168.38μVs, and the average value of the left vertical spine muscles in the air stage of first-class athletes is 2218.24μVs. The P value is 0.13, and there is no significant difference between the national athletes and the first level athletes in the left vertical spine muscle integral EMG value after completing the "324C+1D" movement. The average value of the integrated myoelectric value of the right vertical spine muscle in the air stage of national athletes is 2221.86μVs, and the average value of the integrated myoelectric value of the right vertical spine muscle in the air stage of first-class athletes is 2276.04μVs, and the P value is 0.17. There was no significant difference between the national athletes and the first level athletes in the integration of the right vertical spine muscle in the air stage of "324C+1D" movement.

3.2.5 Comparative analysis and summary of technical characteristics in the flight stage

(1) There is no significant difference between national athletes and first-class athletes in the time spent in the air stage, the time spent from the ground to the slap stage, and the time spent from the slap to the landing stage.

(2) There is no significant difference between the peak value of right leg swing speed before hitting, the peak value of right leg swing speed at hitting moment and the peak value of right leg swing speed after hitting.

(3) There is no significant difference between national athletes and first-class athletes in the angular velocity of the shoulder axis at the moment of striking, the peak angular velocity of the shoulder axis after striking, and the angular velocity of the shoulder axis at the moment of landing.

(4) There is no significant difference between the vertical speed of the center of gravity before the stroke in the air stage and the vertical speed of the center of gravity at the moment of the stroke.

(5) There is no significant difference between the vertical height of the center of gravity at the time of departure from the ground and the vertical height of the center of gravity at the time of landing between national athletes and first-level athletes.

(6) There is no significant difference between the lifting distance of the center of gravity and the falling distance of the center of gravity of the national athletes and the first-class athletes in the air stage.

(7) The muscle activation sequence of national athletes and first-level athletes who completed the "324C+1D" movement in the air stage showed a high consistency, and the difference in the integrated electromyography value of related muscles was not significant.

To sum up, there is no significant difference in the sports biomechanical characteristics of national athletes and first-class athletes in the air stage of completing "324C+1D" movements.

3.3 Comparative analysis of technical characteristics in landing stage

3.3.1 Comparative analysis of link motion features

3.3.1.1 Comparative analysis of shoulder and foot torsion Angle characteristics

Table 74 Shoulder-foot torsion Angle at landing time (°)

Action moment	Group	$\overline{X} \pm S$	P
Landing stage Landing moment	N	20. 18±7. 21	0. 05
	F	29. 19±8. 57	

From the perspective of the shoulder-foot torsion Angle at the landing moment when athletes complete the "324C+1D" movement landing stage (see Table 74), the average shoulder-foot torsion Angle at the landing moment of national athletes is 20.18°, and the average shoulder-foot torsion Angle at the landing moment of first-class athletes is 29.19°, and the P value is 0.05. There is no significant difference in the Angle of shoulder and foot torsion between the national athletes and the first level athletes.

3.3.1.2 Comparative analysis of knee fan Angle characteristics

Table 75 Knee sector Angle during landing cushion stage (°)

Joint	Group	$\overline{X} \pm S$	P
Left knee	N	62.11±26.11	0.53
	F	66.80±20.69	
Right knee	N	21.30±11.05	0.19
	F	60.56±30.15	

From the perspective of knee joint sector Angle of athletes completing the landing buffer stage of "324C+1D" movement (see Table 75), the average knee joint sector Angle of national athletes in the landing buffer stage is 62.11°, and that of first-level athletes in the landing buffer stage is 66.80°, and the P value is 0.53. There is no significant difference in knee fan Angle between national athletes and first level athletes during landing cushion stage.

3.3.2 Comparative analysis of gravity center motion characteristics

3.3.2.1 Comparative analysis of vertical velocity characteristics of the center of gravity at the moment of landing

Table 76 Vertical Velocity of center of gravity at landing (m/s)

Group	$\overline{X} \pm S$	P
N	−3.36±0.44	0.39
F	−3.17±0.28	

From the vertical speed of the center of gravity at the landing moment of the athlete completing the "324C+1D" movement in the landing stage (see Table 76), the average vertical speed of the center of gravity at the landing moment of the national athlete is -3.36m /s, and the average vertical speed of the center of gravity at the landing moment of the first-level athlete is -3.17m /s, and the P value is 0.39. There is no significant difference in the vertical velocity of the center of gravity at the landing moment between the national athletes and the first level athletes.

3.3.2.2 Comparative analysis of vertical movement distance characteristics of the center of gravity in the landing buffer stage

Table 77 Vertical movement distance of Center of gravity in landing buffer stage (m)

Group	$\overline{X} \pm S$	P
N	0. 44±0. 11	0. 66
F	0. 39±0. 09	

From the perspective of the vertical movement distance of the center of gravity during the landing buffer stage of athletes' "324C+1D" movement (see Table 77), the average vertical movement distance of the center of gravity during the landing buffer stage of national athletes is 0.44m, and the average vertical movement distance of the center of gravity during the landing buffer stage of first-level athletes is 0.39m, and the P value is 0.66. There is no significant difference in the vertical movement distance of the center of gravity between the national athletes and the first level athletes.

3.3.3 Comparative analysis of EMG characteristics

According to the test results, not all of the 12 muscles selected for testing in this movement stage participated in the work, and only part of the muscles showed activation state. In this study, only the muscles showing activation state were selected for muscle activation sequence (activation time) analysis and integrated electromyography analysis.

3.3.3.1 Comparative analysis of the activation sequence (activation time) of relevant muscles in the landing stage

From the activation sequence of muscle related to landing stage of national athletes completing "324C+1D" movement (see Figure 32) and the activation sequence of muscle related to landing stage of first-level athletes completing "324C+1D" movement (see Figure 33), The order of muscle activation in landing stage of national athletes and the order of muscle activation in landing stage of first-level athletes showed a high consistency. The left external oblique muscle was activated almost at the same time as the lower extremity extensor muscle, and the activation time was slightly longer than the activation time of the lower extremity extensor muscle, indicating that the "324C+1D" movement still needed to activate the trunk rotator muscle to complete the subsequent trunk rotation after landing. In the landing stage of the "324C+1D" movement, the activation time of the left and right leg gastrocnemius muscle and the right and left thigh rectus muscle is relatively close, and the activation time is longer.

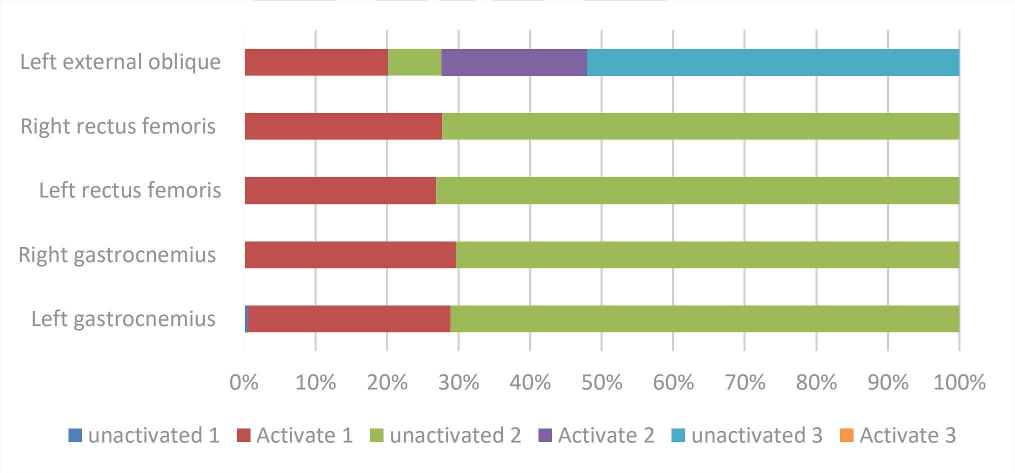

Figure 32 Sequence diagram of muscle activation in landing stage of national athletes

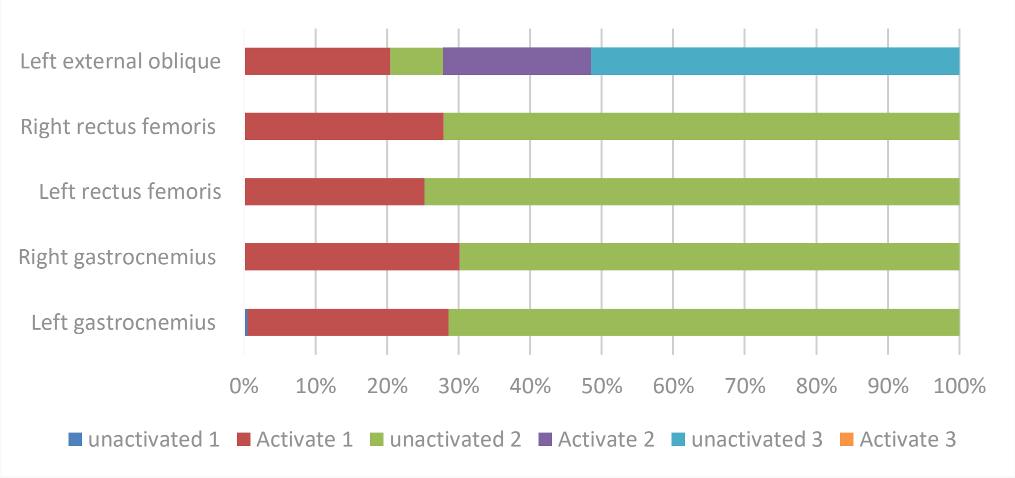

Figure 33 Sequence diagram of muscle activation in first-level athletes at landing stage

3.3.3.2 Comparative analysis of integrated EMG values of relevant muscles in landing stage

Table 78 Integrated Emg value of relevant muscles in the flight stage (μVs)

Muscle	Group	$\overline{X} \pm S$	P
Left gastrocnemius	N	1258. 74±2. 71	0. 65
	F	1277. 21±62. 41	
Right gastrocnemius	N	509. 35±8. 96	0. 61
	F	527. 92±62. 43	
Left rectus femoris	N	1240. 70±6. 00	0. 81
	F	1231. 02±66. 82	
Right rectus femoris	N	898. 45±4. 18	0. 97
	F	896. 85±61. 07	
Left external oblique	N	588. 55±7. 01	0. 53
	F	576. 67±34. 24	

According to the integrated EMG values of the gastrocnemius of the left leg and the gastrocnemius of the right leg after athletes complete the landing stage of "324C+1D" movement (see Table 78), the average value of the integrated EMG values of the gastrocnemius of the left leg during the landing stage of national athletes is 1258.74μVs, and the average value of the integrated EMG values of the gastrocnemius of the left leg during the landing stage of first-level athletes is 1277.21 μVs. The P value is 0.65, and there is no significant difference between the national athletes and the first-level athletes in the left leg gastrocnemius integral EMG value after the landing stage of "324C+1D" movement. The average value of the integrated EMG of the right leg gastrocnemius in the landing stage of national athletes was 509.35μVs, and the average value of the integrated EMG of the right leg gastrocnemius in the landing stage of first-class athletes was 527.92μVs, and the P value was 0.61. There was no significant difference between the national athletes and the first level athletes in the integrated EMG value of the gastrocnemius muscle of the right leg after the landing stage of "324C+1D" movement.

From the point of view of the integrated EMG value of the left and right rectus femoris muscle of the athlete completing the "324C+1D" movement landing stage (see Table 78), the average value of the integrated EMG value of the left rectus femoris muscle of the national athlete landing stage is 1240.70μVs, and the average value of the integrated EMG value of the left rectus femoris of the first-level athlete landing stage is 1231.02μVs. The P value is 0.81, and there is no significant difference between the national athletes and the first-level athletes in the integrated EMG value of the left thigh rectum muscle after the landing stage of "324C+1D" movement. The average value of the integrated EMG of the right rectus femoris muscle in the landing stage of national athletes is 898.45μVs, and the average value of the integrated EMG of the right rectus femoris in the landing stage of first-class athletes is 896.85μVs, and the P value is 0.97. There is no significant difference between the national athletes and the first level athletes in the integrated EMG value of the right thigh rectus muscle after "324C+1D" movement landing stage.

From the point of view of the integrated EMG value of the left external oblique muscle of the athlete completing the landing stage of "324C+1D" movement (see Table 78), the average value of the integrated EMG value of the left external oblique muscle of the national athlete during the landing stage is 588.55μVs, and the average value of the left external oblique muscle of the first-level athlete during the landing stage is 576.67μVs. The P value was 0.53, and there was no significant difference in the integrated EMG value of the left external oblique muscle of the abdomen between the national athletes and the first-level athletes at the landing stage of "324C+1D" movement.

3.3.4 Comparative analysis and summary of technical characteristics in the landing stage

(1) There is no significant difference in shoulder-foot torsion Angle between national athletes and first-class athletes at the landing stage.

(2) There is no significant difference in knee fan Angle between national athletes and first-level athletes during landing cushion stage.

(3) There is no significant difference in the vertical speed of the center of gravity at the landing moment between national athletes and first-class athletes.

(4) There is no significant difference in the vertical movement distance of the center of gravity between national athletes and first-class athletes during the landing buffer stage.

(5) The muscle activation sequence of national athletes and first-level athletes after completing the landing stage of "324C+1D" movement showed a high consistency, and the difference of the integrated electromyography value of related muscles was not significant.

To sum up, there is no significant difference in the sports biomechanical characteristics of the landing stage of the "324C+1D" movement between national athletes and first-class athletes.

CHAPTER V

DISCUSSIONS AND CONCLUSIONS

This chapter discusses the results based on the three objectives of the study and summarizes the conclusions of the study. This chapter is divided into the following two parts: The first part discusses the influence on the "324C+1D" movement according to the stage of the movement according to the kinematic data, jumping force value, EMG data results and biomechanical characteristics of the difficult movement "324C+1D" completed by national wushu athletes and first-level wushu athletes. The practical value of this study, the shortcomings of this study and the future research direction are discussed to provide support for scholars to engage in biomechanics research. The second part summarizes the conclusion of this study.

Discussion

A complete motion technique is composed of different technical links. For example, the "324C+1D" action is composed of four technical links, including running, jumping, flying and landing, each technical link contains specific body movements, which interact and influence each other, and jointly serve the complete sports technology goal to achieve the best sports technology performance.

Discussion on the biomechanical characteristics of Difficult movements “324C+1D” completed by national athletes

1. The impact of national athletes' run-up on the "324C+1D" movement

The technical characteristics of national athletes in the run-up stage of completing the "324C+1D" movement are mainly shown as follows: (1) In the run-up stage, from reaching the peak of the center of gravity speed in the run-up direction to the end of the jump stage, the center of gravity of the human body is decelerating. (2) In the run-up stage, the "324C+1D" movement does not have high requirements for the run-up speed, but appropriately increasing the center of gravity speed in the run-up direction within this speed range may still be conducive to the completion of the "324C+1D" movement. (3) In the run-up stage, the center of gravity speed of the "324C+1D" movement in the run-up direction loses a lot at the time of departure from the ground, and athletes generally increase the stride length as much as possible to improve the speed, and the larger stride length forms a larger shoulder and hip torsion Angle.

In the run-up stage, the loss of the center of gravity speed obtained by the "324C+1D" action in the run-up direction in the take-off stage is mainly caused by the braking component impulse generated after the landing of the jumping foot, and the acceleration of the run-up speed increases the braking impulse accordingly. Therefore, the acceleration of the run-up speed increases the muscle load of the jumping leg during braking, so that the jumping leg exerts greater force on the ground, and then obtains greater ground reaction force, which is conducive to improving the push and stretch strength of the lower limbs and the jumping speed. On the other hand, the increase in the muscle load of the jumping leg often causes a corresponding increase in the centrifugal contraction force of the lower extremity extensor (concessional work). This phenomenon is conducive to converting the kinetic energy obtained in the run-up into the elastic potential energy of the muscle and storing it, and releasing it in the take-off and extension (centripetal contraction) action immediately afterwards, converting this potential energy into kinetic energy, and increasing the contraction force and contraction speed of the muscle in the process of mutual conversion of kinetic energy and potential energy. In addition, during the centrifugal contraction of the extensor muscle, the muscle spindle is stimulated to produce stretch reflex, which further strengthens the centrional contraction of the extensor muscle. Under the combined action of muscle elastic potential energy and stretch reflex, it is more conducive to increasing the push and stretch force of the lower limbs and shortening the jump time. Since the "324C+1D" action is to jump with both feet, the push and stretch strength is more sufficient, which makes up for the lack of the run-up speed, resulting in the "324C+1D" action is not high in the run-up speed.

It is worth noting that speeding up the run-up speed will also put forward higher requirements for the athletes' take-off braking ability. When the run-up speed exceeds the athletes' matching braking ability range, it will lead to the athletes' difficulty in grasping the best time to take off, resulting in insufficient take-off push and stretch, which will affect the take-off effect and the formation of the best take-off Angle. In addition, athletes may also dissipate more energy to control the center of gravity of the body in order to overcome the fast run-up speed, which will also affect the continuity of the action, lead to the extension of the jump time, restrict the play of the elastic potential energy of the lower limb muscle group, and affect the push and stretch strength and the jump effect. Therefore, in sports practice, the run-up speed is restricted by the special technical goal and the athlete's ability.

2. Impact of national athletes' jumping on "324C+1D" movements

The technical characteristics of the national athletes in the take-off stage of the "324C+1D" movement are mainly shown as follows: (1) The national athletes in the take-off stage of the squat movement is larger. (2) National athletes have obvious hip flexion during the take-off, push and stretch stage. (3) The vertical movement distance of the center of gravity of the "324C+1D" action in the take-off and push stage is not the larger the better or the smaller the better, but in a moderate range. (4) After the vertical speed of the center of gravity of the "324C+1D" movement reaches a higher level in the take-off and push and stretch stage, it fluctuates in a small range, which is not the key to affecting the completion of the movement of the athlete. (5) Increasing the vertical reaction force of the ground in the take-off, push and stretch stage is conducive to the completion of the movement of the athletes on the one hand; On the other hand, when the vertical reaction force of the ground reaches a high value, a slight increase or decrease in a small range does not affect the athlete's completion of the movement. (6) The "324C+1D" action has a small center of gravity speed and a center of gravity lifting Angle greater than 70° in the run-up direction at the time of pushing off the ground.

According to the law of momentum, in order to obtain a larger initial velocity, the working distance of the force should be extended as far as possible while ensuring the maximum strength of the muscle. When the working distance reaches the maximum, the working distance should be completed in the shortest time to obtain the maximum speed (Lu, 2010) . The centrifugal contraction of lower limb extensor muscle before take-off, for the centripetal contraction of take-off, take-off and extension stage, is to increase the initial length before contraction, extend the work distance and force time of take-off and extension stage, which is conducive to increasing the push and extension force of lower limb extensor muscle and take-off speed. However, according to the relationship between initial length and muscle contraction force, the muscle contraction force increases in a certain range with the increase of initial length. When the initial length increases to a certain extent, the muscle contraction force reaches the maximum, and then the continuous increase of initial length will cause the decline of muscle contraction force (Wang, 2007) . Therefore, the ankle joint and the knee joint are not squatting as low as possible, but in a moderate joint Angle range, by increasing the muscle contraction force and accelerating the push and stretch speed, in order to achieve the best jumping effect. The aggravation of right hip flexion of national athletes at the moment of leaving the ground when they complete the "324C+1D" movement; To a certain extent, the vertical height of the center of gravity at the time of leaving the ground is reduced, which is conducive to increasing the vertical movement distance of the center of gravity at the stage of lifting. In addition, hip flexion when off the ground is beneficial to reduce the swing amplitude and shorten the swing time after lifting.

"324C+1D" action In the process of rapid squatting, the lower limb extensor muscles perform rapid centrifugal contraction, the elastic potential energy of the muscle is stored in this process, and is released in the subsequent push and stretch (centrional contraction), the potential energy is converted into kinetic energy, which is conducive to increasing the centrional contraction force and contraction speed of the muscle. At the same time of centrifugal contraction of the extensor muscle, the muscle spindle is stimulated to produce stretch reflex, which further strengthens the subsequent centripetal contraction of the extensor muscle. Under the combined action of muscle elastic potential energy and stretch reflex, it is more conducive to increasing the push and stretch force of the lower limbs and shortening the push and stretch time. In addition, the play of muscle elastic potential energy is affected by the speed of the "elongation-shortening" cycle, and the slower speed will lead to the decrease of tension and relaxation in the process of muscle elongation, and reduce the elastic retraction force during centripetal contraction. Therefore, speeding up the jumping speed, improving the consistency of jumping squat and jumping push and stretch, and shortening the jumping time are conducive to the athletes to complete the "324C+1D" movement.

In the take-off stage, the joint fan Angle in the lower limb joint linkage process affects the vertical movement distance of the center of gravity and the vertical speed of the center of gravity. The joint flexion at the time of lift-off also offends the vertical rise speed of the center of gravity to a certain extent. Therefore, the vertical movement distance of the center of gravity and the vertical speed of the center of gravity in the take-off, push and stretch stage also show that the larger the better or the smaller the better. It's in a moderate range. In addition, when the vertical speed of the center of gravity reaches a higher level, the athlete puts more energy into the rotation rather than the jump height in order to complete the "324C+1D" movement.

The technical requirements of "324C+1D" action in competitive martial arts routine competition determine the maximum demand for lifting distance and holding time in the air, and the speed of the center of gravity in different directions at the time of leaving the ground determines the lifting Angle of the center of gravity and the trajectory of the movement in the air. The gain of vertical speed is based on the loss of horizontal speed, and it is impossible to have a take-off technology with little horizontal speed loss and large vertical speed gain (Lu, 2010) . Therefore, the interaction between the loss of horizontal velocity and the gain of vertical velocity results in the formation of the lifting Angle of the center of gravity at the time of liftoff (Arthur E & Chapman, 2010) . From the perspective of "324C+1D" movement, the speed of the center of gravity in the run-up direction at the time of departure from the ground is small, and the lifting Angle is close to 90°, which determines that the center of gravity of the human body in the airborne stage of "324C+1D" movement is approximately straight up and down. According to the projectile formula (Tan, 2009) , If other conditions remain unchanged, the lifting Angle of the center of gravity at 90° can obtain the highest lifting height, so the "324C+1D" action should try to convert the run-up speed into the largest vertical speed as possible in the jumping stage.

3. Influence of torso rotation, arm swing and leg swing on "324C+1D" movements before flying

The main features of the torso rotation, arm swing and leg swing before the "324C+1D" movement are as follows: (1) Appropriately increase the shoulder-hip torsion Angle before the "324C+1D" movement and the shoulder-foot torsion Angle at the time of leaving the ground, which is conducive to the athletes to complete the movement. (2) The peak arm swing speed of "324C+1D" movement in the jumping stage is larger.

To a certain extent, the reverse rotation amplitude of the trunk and the reverse swing amplitude of the arm before the take-off and push out can make the rotator muscle group of the trunk and the swing muscle group of the arm centrifugal and elongate, which is beneficial to store more muscle elastic potential energy and release it in the subsequent reverse acceleration movement, converting the potential energy into kinetic energy and increasing the centripetal contraction force of the muscle. In addition, the centrifugal elongation of trunk rotator muscle group and arm swing muscle group increases the initial length of muscle before centripetal contraction, increases the work distance of muscle centripetal contraction, and prolongs the action time, which is conducive to the increase of impulse moment and the rotation speed of swing arm and trunk. The shoulder and foot torsion Angle at the moment of departure from the ground is the result of the rotation of the torso before takeoff. The increase of the Angle reduces the rotation Angle needed to complete after takeoff to a certain extent. Therefore, athletes usually maximize the shoulder and foot torsion Angle before takeoff in difficult movements.

In the "324C+1D" movement, the arm of the national athletes presents an accelerated arc swing from the bottom to the top, and the arm swing speed increases with the difficulty level. According to Newton's laws of mechanics, the swinging arm movement produces opposite and equal reaction force, which is transmitted through other connecting parts of the body and acts on the jumping leg. While increasing the load of the jumping leg, it also increases the pushing force of the jumping leg against the ground, thus obtaining greater ground reaction force. When the swing arm and leg speed reach the maximum, the upward swing arm and leg motion quickly decelerate and brake. Under the upward inertia trend, the muscle load of the jumping leg is reduced, which is conducive to the lower limb overcoming its own gravity faster in the push and stretch stage, and the jumping speed is increased. According to Newton's laws of mechanics, "the reaction force of two objects is equal, in the opposite direction, along the same straight line, and respectively acts on two objects to produce their own effects," the most conducive to "jump high" swing arm, swing leg technology, should be the arm and left leg in front of the body quickly and powerfully from the bottom up, rather than from the bottom to the top of the arc swing. This shows that the swing of the arms and legs in the "324C+1D" movement is not only to "jump high" but also to be fully prepared for "turn fast".

According to the law of conservation of moment of momentum, the condition of conservation of moment of momentum is satisfied when the human body is in a state of unsupported vacation (Lu, 2010) . Therefore, in order to complete the turning action in the air, it is necessary to obtain the moment of momentum (angular momentum) to make the body rotate in the state of take-off support (Gong & Wang, 2013) . When the national athletes complete the "324C+1D" action, in the support state before flying, they obtain a moment of momentum (angular momentum) that makes the body rotate around the vertical axis through the movement of the torso, the swing arm and the swing leg. If they want to increase the angular momentum before flying, according to the relationship among angular momentum, angular velocity and moment of inertia, Athletes in the jumping support state of the swing arm, swing leg movement trajectory should be as close to the horizontal plane as possible, extend the elbow, straight knee swing, so that the swinging body as far as possible away from the trunk, increase the moment of inertia, and increase the muscle strength to speed up the swing arm, swing leg speed, in order to obtain greater angular momentum.

It is worth noting that: (1) In the reverse movement of the turn and swing arm, it is necessary to strengthen the coherence of the action, shorten the transition time from muscle extension to contraction as much as possible, maximize the use of the elastic potential energy of the muscle, and increase the centripetal contraction force of the muscle. (2) It is necessary to take into account the best range of the reverse movement. According to the relationship between the initial length and the strength curve, the increase of the initial length is not the greater the better. When the muscle strength reaches the maximum with the increase of the initial length, the further increase of the initial length will cause the muscle strength to decline; In addition, the rotation and swing arm action should be combined with the push and stretch jumping action, and the pursuit of increasing the work distance of the rotation and swing arm and extending the action time will inevitably affect the jumping speed and jumping time. Therefore, the best turning and swinging arm program is to speed up the take-off speed and shorten the take-off time, while ensuring a certain pre-stretching amplitude, speeding up the turning and swinging arm speed, so as to obtain a larger initial speed and angular momentum of the turning body, creating favorable conditions for the completion of the "324C+1D" movement of the airborne turning movement. (3) According to the relationship between angular momentum and moment of inertia, moment of inertia and axis distance, and action and reaction force, the motion trajectory of swing arm and leg in the take-off stage regulates the contradictory technical action task of "jumping higher" or "turning faster" to a certain extent, and takes both into account to a certain extent. It reflects the ability of high-level athletes to control the Angle of limb swing.

4. Influence of air attitude change on the movement of "324C+1D"

When the human body is in the air, the moment of momentum is conserved, and the human body is only subject to the action of gravity, and the internal force of the human body can only produce the relative motion of the body links, and cannot change the movement trajectory of the whole body's center of gravity (Sports biomechanics writing group, 2013) . However, the human body can change the moment of inertia with the help of changes in air posture and relative movement of links, so as to realize the transfer of the moment of momentum between basic axes and the change of the rotational speed of the body (Lu, 2010) .

"324C+1D" movement in the air stage mainly includes: swing leg stroke, swing leg pressure, bending arms to chest, turning head and twisting waist, and leg rotation, arm spread leg and other changes in air posture. The main technical characteristics of these air movements are as follows: (1) the athlete has a certain angular rotational speed of the shoulder shaft at the moment of hitting when completing the "324C+1D" movement in the air stage; after hitting, the angular rotational speed of the shoulder shaft increases to the peak level, and the angular rotational speed of the shoulder shaft decreases, and a certain angular rotational speed of the shoulder shaft is maintained at the moment of landing. (2) The vertical height of the center of gravity at the moment of take-off from the ground when the national athlete completes the "324C+1D" movement is greater than the vertical height of the center of gravity at the moment of landing, so the vertical movement distance of the center of gravity rising is less than the vertical movement distance of the center of gravity falling.

From the perspective of the influence of the change of body posture on the moment of inertia and angular velocity, in the stage from the ground to the beating action, the right leg and left hand are far away from the trunk due to the arc swing of the right leg and the extended arm of the left hand, resulting in the increase of moment of inertia and the slow angular velocity of the trunk around the vertical axis. After the stroke, the right leg is accelerated to press down and close to the left leg, while the two arms bend the elbow to the chest, so that the body is close to the trunk, and the rotation radius of the limb around the vertical axis is shortened in the process of this movement, resulting in the reduction of the moment of inertia, and the angular speed of the trunk around the vertical axis is accelerated. Therefore, speeding up the swing speed of the right leg before the stroke is conducive to shortening the time of the action stage with the increase of the moment of inertia, and reserving more time for the action stage with the small moment of inertia after the stroke, which is conducive to the athlete completing a larger rotation Angle in the air stage.

In the process of center of gravity fall, in order to connect the horse step action after landing, the two legs need to be separated before landing, so that the distance between the two feet is increased, usually accompanied by a slight extension of the two arms and elbow extension. On the one hand, this is conducive to creating favorable conditions for the support of the horse after landing; On the other hand, leg splitting and arm spreading move the limbs away from the torso, resulting in increased moment of inertia and slower rotation speed, which is conducive to reducing the rotational inertia after landing. Of course, this attitude change is in the trunk speed and stagnation time to ensure that the athlete can complete the required rotation Angle, if the speed or stagnation time is insufficient, the athlete will try to maintain the bending arm chest, and leg rotation (rotation speed is faster) in the center of gravity drop stage in order to complete the larger rotation Angle, and delay the action time of leg splitting. In addition, it will delay the time of foot landing by increasing the flexion of the hip, knee and ankle joints to achieve the purpose of increasing the falling distance and holding time, which will lead to problems such as the vertical center of gravity at the time of landing, the trunk speed is too fast, and the distance between the two feet is too small.

It is worth noting that the change of body posture in the air should minimize the excess shaking of the torso caused by the relative movement of the body link to avoid adverse effects on the smooth rotation of the body. In addition, from the perspective of the trunk shape in the air stage, in the process of completing the air movement, try to make the trunk and the rotating axis, that is, the trunk is close to the vertical axis, in order to shorten the rotation radius, reduce the moment of inertia, and increase the angular speed of the air rotation, which is not only conducive to the athletes in the air stage to complete a greater degree of rotation, but also to improve the completion quality of the air movement.

5. Impact of landing connection on "324C+1D" action

The technical characteristics of the national athletes completing the landing stage of the "324C+1D" movement are mainly shown as follows: (1) the shoulder and foot torsion Angle at the landing moment is well controlled, and the national athletes can avoid the shoulder and foot torsion Angle at the landing moment through other compensative mechanisms when completing the "324C+1D" movement. (2) In the landing stage of national athletes, the left knee joint fan Angle is usually larger than the right knee joint fan Angle. (3) When the completion difficulty is within a certain range, national athletes may buffer the impact force after landing by increasing the vertical movement distance of the center of gravity in the landing buffer stage, but when the difficulty exceeds this range of ability, the vertical movement distance of the center of gravity will be reduced. (4) When athletes complete the "324C+1D" movement, they may still bear a large ground reaction force in the landing buffer stage. The reason is that athletes actively reduce the cushioning effect of lower limb centrifugal contraction in order to achieve the perfect technical requirements of "rapid stability" at the moment of landing.

The main technical purpose and task of the landing stage is to ensure the stability of the landing connection. According to the relevant theories of sports biomechanics, the stability of the human body is mainly affected by the following factors: the size of the support surface, the height of the center of gravity, the stability Angle and the stability coefficient. In addition, the stability of the jumping action during the landing stage is also affected by the impact force and muscle braking ability after landing. The leg splitting action before landing determines the distance between the two feet after landing. The size of the supporting area composed of the distance between the two feet affects the stability of the athlete's action after landing to a certain extent. Generally speaking, the supporting surface is large and the stability is large, while the supporting surface is small and the stability is small.

Usually in sports practice, when the difficulty reaches or approaches a certain ability threshold of the athlete, the continued increase of the rotation Angle will be restricted by the rotation speed, air height and air retention time. In order to complete the rotation task with a larger Angle, on the one hand, the athlete will try to maintain the body posture with a faster rotation Angle (with legs and elbows attached to the chest) for a longer time. However, delaying the action time of leg splitting and arm extension leads to insufficient leg and arm extension action at the time of landing, resulting in problems such as too small distance between the two feet after landing, too fast rotation angular speed and too large shoulder and foot twisting Angle, which not only reduces the stability coefficient, but also increases the difficulty of rotary braking after landing. On the other hand, athletes will increase the curvature of the lower limb joints before landing, reduce the vertical height of the center of gravity at the moment of landing, delay the landing time of the supporting foot, and extend the moving distance and stagnation time of the center of gravity falling vertically. Due to the increase of the moving distance of the center of gravity falling, the action time of gravitational acceleration will be prolonged, and the vertical speed of the center of gravity at the moment of landing will also increase. In addition, reducing the vertical height of the center of gravity at the moment of landing will crowd out the landing buffer distance to a certain extent, and the landing buffer action completed in this state will inevitably lead to the horse step action closer to the squat state, which increases the difficulty of the centrifugal braking of the lower limb extensor muscle, and it is easy to make the horse step action into a wrong posture with a small distance between the feet and a low body center of gravity. The action quality of landing connection is seriously affected.

It is worth noting that: (1) According to Newton's third law, "when two objects interact, the force of object A on object B is equal to the reaction force of object B on object A, in the opposite direction, along the same straight line, and each acts on the two objects to produce their own effects." In the landing buffer stage, the national athletes need to overcome slightly different impact forces when completing the "324C+1D" action, and the movement trajectory in the air is close to straight up and down. (2) The left knee joint fan Angle of "324C+1D" movement in the landing buffer stage is generally larger than that of the right knee joint fan Angle. The reasons are due to special technical characteristics, individual habits of athletes and the difference of braking ability of left and right legs. However, in the buffering process, the difference in the Angle of the left and right limbs joint fan may lead to the deviation of the body gravity action line in the support plane. If the deviation is too large, the gravity action line will be close to the boundary of the support plane or even exceed the boundary of the support plane, which will lead to the failure of the landing connection. Therefore, in the process of landing buffer, we should pay attention to the control of the center of gravity of the body.

Discussion on the biomechanical characteristics of Difficult movements “324C+1D” completed by first level athletes

1. The impact of the run-up of first level athletes on the "324C+1D" movement

The technical characteristics of Level I athletes in the run-up stage of completing the "324C+1D" movement are mainly shown as follows: (1) In the run-up stage, from reaching the peak of the center of gravity speed in the run-up direction to the end of the jump stage, the center of gravity of the human body is decelerating. (2) In the run-up stage, the "324C+1D" movement does not have high requirements for the run-up speed, but appropriately increasing the center of gravity speed in the run-up direction within this speed range may still be conducive to the completion of the "324C+1D" movement. (3) In the run-up stage, the center of gravity speed of the "324C+1D" movement in the run-up direction loses a lot at the time of departure from the ground, and athletes generally increase the stride length as much as possible to improve the speed, and the larger stride length forms a larger shoulder and hip torsion Angle.

In the run-up stage, the loss of the center of gravity speed obtained by the "324C+1D" action in the run-up direction in the take-off stage is mainly caused by the braking component impulse generated after the landing of the jumping foot, and the acceleration of the run-up speed increases the braking impulse accordingly. Therefore, the acceleration of the run-up speed increases the muscle load of the jumping leg during braking, so that the jumping leg exerts greater force on the ground, and then obtains greater ground reaction force, which is conducive to improving the push and stretch strength of the lower limbs and the jumping speed. On the other hand, the increase in the muscle load of the jumping leg often causes a corresponding increase in the centrifugal contraction force of the lower extremity extensor (concessional work). This phenomenon is conducive to converting the kinetic energy obtained in the run-up into the elastic potential energy of the muscle and storing it, and releasing it in the take-off and extension (centripetal contraction) action immediately afterwards, converting this potential energy into kinetic energy, and increasing the contraction force and contraction speed of the muscle in the process of mutual conversion of kinetic energy and potential energy. In addition, during the centrifugal contraction of the extensor muscle, the muscle spindle is stimulated to produce stretch reflex, which further strengthens the centrional contraction of the extensor muscle. Under the combined action of muscle elastic potential energy and stretch reflex, it is more conducive to increasing the push and stretch force of the lower limbs and shortening the jump time. Since the "324C+1D" action is to jump with both feet, the push and stretch strength is more sufficient, which makes up for the lack of the run-up speed, resulting in the "324C+1D" action is not high in the run-up speed.

It is worth noting that speeding up the run-up speed will also put forward higher requirements for the athletes' take-off braking ability. When the run-up speed exceeds the athletes' matching braking ability range, it will lead to the athletes' difficulty in grasping the best time to take off, resulting in insufficient take-off push and stretch, which will affect the take-off effect and the formation of the best take-off Angle. In addition, athletes may also dissipate more energy to control the center of gravity of the body in order to overcome the fast run-up speed, which will also affect the continuity of the action, lead to the extension of the jump time, restrict the play of the elastic potential energy of the lower limb muscle group, and affect the push and stretch strength and the jump effect. Therefore, in sports practice, the run-up speed is restricted by the special technical goal and the athlete's ability.

2. The impact of the take-off of Class I athletes on the "324C+1D" movement

The technical characteristics of the first-level athletes in the take-off stage of the "324C+1D" movement are mainly shown as follows: (1) The squat movement of the first-level athletes in the take-off stage is larger. (2) The hip flexion phenomenon of first-level athletes is more obvious in the take-off, push and stretch stage. (3) The vertical movement distance of the center of gravity of the "324C+1D" action in the take-off and push stage is not the larger the better or the smaller the better, but in a moderate range. (4) After the vertical speed of the center of gravity of the "324C+1D" movement reaches a higher level in the take-off and push and stretch stage, it fluctuates in a small range, which is not the key to affecting the completion of the movement of the athlete. (5) Increasing the vertical reaction force of the ground in the take-off, push and stretch stage is conducive to the completion of the movement of the athletes on the one hand; On the other hand, when the vertical reaction force of the ground reaches a high value, a slight increase or decrease in a small range does not affect the athlete's completion of the movement. (6) The "324C+1D" action has a small center of gravity speed and a center of gravity lifting Angle greater than 70° in the run-up direction at the time of pushing off the ground.

According to the law of momentum, in order to obtain a larger initial velocity, the working distance of the force should be extended as far as possible while ensuring the maximum strength of the muscle. When the working distance reaches the maximum, the working distance should be completed in the shortest time to obtain the maximum speed (Lu, 2010) . The centrifugal contraction of lower limb extensor muscle before take-off, for the centripetal contraction of take-off, take-off and extension stage, is to increase the initial length before contraction, extend the work distance and force time of take-off and extension stage, which is conducive to increasing the push and extension force of lower limb extensor muscle and take-off speed. However, according to the relationship between initial length and muscle contraction force, the muscle contraction force increases in a certain range with the increase of initial length. When the initial length increases to a certain extent, the muscle contraction force reaches the maximum, and then the continuous increase of initial length will cause the decline of muscle contraction force (Wang, 2007) . Therefore, the ankle joint and the knee joint are not squatting as low as possible, but in a moderate joint Angle range, by increasing the muscle contraction force and accelerating the push and stretch speed, in order to achieve the best jumping effect. The aggravation of the right hip flexion at the moment of leaving the ground when the Level I athletes complete the "324C+1D" movement; To a certain extent, the vertical height of the center of gravity at the time of leaving the ground is reduced, which is conducive to increasing the vertical movement distance of the center of gravity at the stage of lifting. In addition, hip flexion when off the ground is beneficial to reduce the swing amplitude and shorten the swing time after lifting.

"324C+1D" action In the process of rapid squatting, the lower limb extensor muscles perform rapid centrifugal contraction, the elastic potential energy of the muscle is stored in this process, and is released in the subsequent push and stretch (centrional contraction), the potential energy is converted into kinetic energy, which is conducive to increasing the centrional contraction force and contraction speed of the muscle. At the same time of centrifugal contraction of the extensor muscle, the muscle spindle is stimulated to produce stretch reflex, which further strengthens the subsequent centripetal contraction of the extensor muscle. Under the combined action of muscle elastic potential energy and stretch reflex, it is more conducive to increasing the push and stretch force of the lower limbs and shortening the push and stretch time. In addition, the play of muscle elastic potential energy is affected by the speed of the "elongation-shortening" cycle, and the slower speed will lead to the decrease of tension and relaxation in the process of muscle elongation, and reduce the elastic retraction force during centripetal contraction. Therefore, speeding up the jumping speed, improving the consistency of jumping squat and jumping push and stretch, and shortening the jumping time are conducive to the athletes to complete the "324C+1D" movement.

In the take-off stage, the joint fan Angle in the lower limb joint linkage process affects the vertical movement distance of the center of gravity and the vertical speed of the center of gravity. The joint flexion at the time of lift-off also offends the vertical rise speed of the center of gravity to a certain extent. Therefore, the vertical movement distance of the center of gravity and the vertical speed of the center of gravity in the take-off, push and stretch stage also show that the larger the better or the smaller the better. It's in a moderate range. In addition, when the vertical speed of the center of gravity reaches a higher level, the athlete puts more energy into the rotation rather than the jump height in order to complete the "324C+1D" movement.

The technical requirements of "324C+1D" action in competitive martial arts routine competition determine the maximum demand for lifting distance and holding time in the air, and the speed of the center of gravity in different directions at the time of leaving the ground determines the lifting Angle of the center of gravity and the trajectory of the movement in the air. The gain of vertical speed is based on the loss of horizontal speed, and it is impossible to have a take-off technology with little horizontal speed loss and large vertical speed gain (Lu, 2010) . Therefore, the interaction between the loss of horizontal velocity and the gain of vertical velocity results in the formation of the lifting Angle of the center of gravity at the time of liftoff (Arthur E & Chapman, 2010) [97]. From the perspective of "324C+1D" movement, the speed of the center of gravity in the run-up direction at the time of departure from the ground is small, and the lifting Angle is close to 90°, which determines that the center of gravity of the human body in the airborne stage of "324C+1D" movement is approximately straight up and down. According to the projectile formula (Tan, 2009) , If other conditions remain unchanged, the lifting Angle of the center of gravity at 90° can obtain the highest lifting height, so the "324C+1D" action should try to convert the run-up speed into the largest vertical speed as possible in the jumping stage.

3. Influence of torso rotation, arm swing and leg swing before lifting on "324C+1D" movement

The main features of the torso rotation, arm swing and leg swing before the "324C+1D" movement are as follows: (1) Appropriately increase the shoulder-hip torsion Angle before the "324C+1D" movement and the shoulder-foot torsion Angle at the time of leaving the ground, which is conducive to the athletes to complete the movement. (2) The peak arm swing speed of "324C+1D" movement in the jumping stage is larger.

To a certain extent, the reverse rotation amplitude of the trunk and the reverse swing amplitude of the arm before the take-off and push out can make the rotator muscle group of the trunk and the swing muscle group of the arm centrifugal and elongate, which is beneficial to store more muscle elastic potential energy and release it in the subsequent reverse acceleration movement, converting the potential energy into kinetic energy and increasing the centripetal contraction force of the muscle. In addition, the centrifugal elongation of trunk rotator muscle group and arm swing muscle group increases the initial length of muscle before centripetal contraction, increases the work distance of muscle centripetal contraction, and prolongs the action time, which is conducive to the increase of impulse moment and the rotation speed of swing arm and trunk. The shoulder and foot torsion Angle at the moment of departure from the ground is the result of the rotation of the torso before takeoff. The increase of the Angle reduces the rotation Angle needed to complete after takeoff to a certain extent. Therefore, athletes usually maximize the shoulder and foot torsion Angle before takeoff in difficult movements.

In the "324C+1D" movement, the arm of the first-level athletes presents an accelerated arc swing from the bottom to the top, and the arm swing speed increases with the difficulty level. According to Newton's laws of mechanics, the swinging arm movement produces opposite and equal reaction force, which is transmitted through other connecting parts of the body and acts on the jumping leg. While increasing the load of the jumping leg, it also increases the pushing force of the jumping leg against the ground, thus obtaining greater ground reaction force. When the swing arm and leg speed reach the maximum, the upward swing arm and leg motion quickly decelerate and brake. Under the upward inertia trend, the muscle load of the jumping leg is reduced, which is conducive to the lower limb overcoming its own gravity faster in the push and stretch stage, and the jumping speed is increased. According to Newton's laws of mechanics, "the reaction force of two objects is equal, in the opposite direction, along the same straight line, and respectively acts on two objects to produce their own effects," the most conducive to "jump high" swing arm, swing leg technology, should be the arm and left leg in front of the body quickly and powerfully from the bottom up, rather than from the bottom to the top of the arc swing. This shows that the swing of the arms and legs in the "324C+1D" movement is not only to "jump high" but also to be fully prepared for "turn fast".

According to the law of conservation of moment of momentum, the condition of conservation of moment of momentum is satisfied when the human body is in a state of unsupported vacation (Lu, 2010) . Therefore, in order to complete the turning action in the air, it is necessary to obtain the moment of momentum (angular momentum) to make the body rotate in the state of take-off support (Gong & Wang, 2013) . When a first-level athlete completes the "324C+1D" action, in the support state before flying, he obtains a moment of momentum (angular momentum) that makes the body rotate around the vertical axis through trunk rotation, swing arm and swing leg movement. If he wants to increase the angular momentum before flying, according to the relationship between angular momentum, angular velocity and moment of inertia, Athletes in the jumping support state of the swing arm, swing leg movement trajectory should be as close to the horizontal plane as possible, extend the elbow, straight knee swing, so that the swinging body as far as possible away from the trunk, increase the moment of inertia, and increase the muscle strength to speed up the swing arm, swing leg speed, in order to obtain greater angular momentum.

It is worth noting that: (1) In the reverse movement of the turn and swing arm, it is necessary to strengthen the coherence of the action, shorten the transition time from muscle extension to contraction as much as possible, maximize the use of the elastic potential energy of the muscle, and increase the centripetal contraction force of the muscle. (2) It is necessary to take into account the best range of the reverse movement. According to the relationship between the initial length and the strength curve, the increase of the initial length is not the greater the better. When the muscle strength reaches the maximum with the increase of the initial length, the further increase of the initial length will cause the muscle strength to decline; In addition, the rotation and swing arm action should be combined with the push and stretch jumping action, and the pursuit of increasing the work distance of the rotation and swing arm and extending the action time will inevitably affect the jumping speed and jumping time. Therefore, the best turning and swinging arm program is to speed up the take-off speed and shorten the take-off time, while ensuring a certain pre-stretching amplitude, speeding up the turning and swinging arm speed, so as to obtain a larger initial speed and angular momentum of the turning body, creating favorable conditions for the completion of the "324C+1D" movement of the airborne turning movement. (3) According to the relationship between angular momentum and moment of inertia, moment of inertia and axis distance, and action and reaction force, the motion trajectory of swing arm and leg in the take-off stage regulates the contradictory technical action task of "jumping higher" or "turning faster" to a certain extent, and takes both into account to a certain extent. It reflects the ability of high-level athletes to control the Angle of limb swing.

4. Influence of air attitude change on the movement of "324C+1D"

When the human body is in the air, the moment of momentum is conserved, and the human body is only subject to the action of gravity, and the internal force of the human body can only produce the relative motion of the body links, and cannot change the movement trajectory of the whole body's center of gravity (Sports biomechanics writing group, 2013) . However, the human body can change the moment of inertia with the help of changes in air posture and relative movement of links, so as to realize the transfer of the moment of momentum between basic axes and the change of the rotational speed of the body (Lu, 2010) .

"324C+1D" movement in the air stage mainly includes: swing leg stroke, swing leg pressure, bending arms to chest, turning head and twisting waist, and leg rotation, arm spread leg and other changes in air posture. The main technical characteristics of these air movements are as follows: (1) the athlete has a certain angular rotational speed of the shoulder shaft at the moment of hitting when completing the "324C+1D" movement in the air stage; after hitting, the angular rotational speed of the shoulder shaft increases to the peak level, and the angular rotational speed of the shoulder shaft decreases, and a certain angular rotational speed of the shoulder shaft is maintained at the moment of landing. (2) The vertical height of the center of gravity at the time of take-off from the ground when the athlete completes the "324C+1D" movement is greater than the vertical height of the center of gravity at the time of landing, so the vertical movement distance of the center of gravity rising is less than the vertical movement distance of the center of gravity falling.

From the perspective of the influence of the change of body posture on the moment of inertia and angular velocity, in the stage from the ground to the beating action, the right leg and left hand are far away from the trunk due to the arc swing of the right leg and the extended arm of the left hand, resulting in the increase of moment of inertia and the slow angular velocity of the trunk around the vertical axis. After the stroke, the right leg is accelerated to press down and close to the left leg, while the two arms bend the elbow to the chest, so that the body is close to the trunk, and the rotation radius of the limb around the vertical axis is shortened in the process of this movement, resulting in the reduction of the moment of inertia, and the angular speed of the trunk around the vertical axis is accelerated. Therefore, speeding up the swing speed of the right leg before the stroke is conducive to shortening the time of the action stage with the increase of the moment of inertia, and reserving more time for the action stage with the small moment of inertia after the stroke, which is conducive to the athlete completing a larger rotation Angle in the air stage.

In the process of center of gravity fall, in order to connect the horse step action after landing, the two legs need to be separated before landing, so that the distance between the two feet is increased, usually accompanied by a slight extension of the two arms and elbow extension. On the one hand, this is conducive to creating favorable conditions for the support of the horse after landing; On the other hand, leg splitting and arm spreading move the limbs away from the torso, resulting in increased moment of inertia and slower rotation speed, which is conducive to reducing the rotational inertia after landing. Of course, this attitude change is in the trunk speed and stagnation time to ensure that the athlete can complete the required rotation Angle, if the speed or stagnation time is insufficient, the athlete will try to maintain the bending arm chest, and leg rotation (rotation speed is faster) in the center of gravity drop stage in order to complete the larger rotation Angle, and delay the action time of leg splitting. In addition, it will delay the time of foot landing by increasing the flexion of the hip, knee and ankle joints to achieve the purpose of increasing the falling distance and holding time, which will lead to problems such as the vertical center of gravity at the time of landing, the trunk speed is too fast, and the distance between the two feet is too small.

It is worth noting that the change of body posture in the air should minimize the excess shaking of the torso caused by the relative movement of the body link to avoid adverse effects on the smooth rotation of the body. In addition, from the perspective of the trunk shape in the air stage, in the process of completing the air movement, try to make the trunk and the rotating axis, that is, the trunk is close to the vertical axis, in order to shorten the rotation radius, reduce the moment of inertia, and increase the angular speed of the air rotation, which is not only conducive to the athletes in the air stage to complete a greater degree of rotation, but also to improve the completion quality of the air movement.

5. Impact of Landing connection on the "324C+1D" movement

The technical characteristics of Level I athletes completing the landing stage of the "324C+1D" movement are mainly shown as follows: (1) the shoulder and foot torsion Angle at the landing moment is well controlled, and Level I athletes can avoid the shoulder and foot torsion Angle at the landing moment by other compensative mechanisms when completing the "324C+1D" movement. (2) Level I athletes in the landing stage usually left knee joint fan Angle is larger than the right knee joint fan Angle. (3) When the completion difficulty is within a certain range, Level I athletes may buffer the impact after landing by increasing the vertical movement distance of the center of gravity in the landing buffer stage, but when the difficulty exceeds this range of ability, the vertical movement distance of the center of gravity will be reduced. (4) Level I athletes may still bear large ground reaction forces during the landing buffer stage when completing the "324C+1D" movement. The reason is that athletes actively reduce the cushioning effect of lower limb centrifugal contraction in order to achieve the perfect technical requirements of "rapid stability" at the moment of landing.

The main technical purpose and task of the landing stage is to ensure the stability of the landing connection. According to the relevant theories of sports biomechanics, the stability of the human body is mainly affected by the following factors: the size of the support surface, the height of the center of gravity, the stability Angle and the stability coefficient. In addition, the stability of the jumping action during the landing stage is also affected by the impact force and muscle braking ability after landing. The leg splitting action before landing determines the distance between the two feet after landing. The size of the supporting area composed of the distance between the two feet affects the stability of the athlete's action after landing to a certain extent. Generally speaking, the supporting surface is large and the stability is large, while the supporting surface is small and the stability is small.

Usually in sports practice, when the difficulty reaches or approaches a certain ability threshold of the athlete, the continued increase of the rotation Angle will be restricted by the rotation speed, air height and air retention time. In order to complete the rotation task with a larger Angle, on the one hand, the athlete will try to maintain the body posture with a faster rotation Angle (with legs and elbows attached to the chest) for a longer time. However, delaying the action time of leg splitting and arm extension leads to insufficient leg and arm extension action at the time of landing, resulting in problems such as too small distance between the two feet after landing, too fast rotation angular speed and too large shoulder and foot twisting Angle, which not only reduces the stability coefficient, but also increases the difficulty of rotary braking after landing. On the other hand, athletes will increase the curvature of the lower limb joints before landing, reduce the vertical height of the center of gravity at the moment of landing, delay the landing time of the supporting foot, and extend the moving distance and stagnation time of the center of gravity falling vertically. Due to the increase of the moving distance of the center of gravity falling, the action time of gravitational acceleration will be prolonged, and the vertical speed of the center of gravity at the moment of landing will also increase. In addition, reducing the vertical height of the center of gravity at the moment of landing will crowd out the landing buffer distance to a certain extent, and the landing buffer action completed in this state will inevitably lead to the horse step action closer to the squat state, which increases the difficulty of the centrifugal braking of the lower limb extensor muscle, and it is easy to make the horse step action into a wrong posture with a small distance between the feet and a low body center of gravity. The action quality of landing connection is seriously affected.

It is worth noting that: (1) According to Newton's third law, "when two objects interact, the force of object A on object B is equal to the reaction force of object B on object A, in the opposite direction, along the same straight line, and each acts on the two objects to produce their own effects." In the landing buffer stage, the first-level athletes need to overcome slightly different impact forces when completing the "324C+1D" action, and the movement trajectory in the air is close to straight up and down. (2) The left knee joint fan Angle of "324C+1D" movement in the landing buffer stage is generally larger than that of the right knee joint fan Angle. The reasons are due to special technical characteristics, individual habits of athletes and the difference of braking ability of left and right legs. However, in the buffering process, the difference in the Angle of the left and right limbs joint fan may lead to the deviation of the body gravity action line in the support plane. If the deviation is too large, the gravity action line will be close to the boundary of the support plane or even exceed the boundary of the support plane, which will lead to the failure of the landing connection. Therefore, in the process of landing buffer, we should pay attention to the control of the center of gravity of the body.

Discuss on the same biomechanical characteristics of Difficult movements “324C+1D” completed by national athletes and first level athletes

1. The impact of athletes' run-up on the "324C+1D" movement

There is no significant difference in biomechanical characteristics between national athletes and first-level athletes in the run-up phase of 324C+1D movements. The technical characteristics are mainly as follows: (1) In the run-up phase, the body's center of gravity slows down from reaching the peak of the center of gravity speed in the run-up direction to the end of the jump phase. (2) In the run-up stage, the "324C+1D" movement does not have high requirements for the run-up speed, but appropriately increasing the center of gravity speed in the run-up direction within this speed range may still be conducive to the completion of the "324C+1D" movement. (3) In the run-up stage, the center of gravity speed of the "324C+1D" movement in the run-up direction loses a lot at the time of departure from the ground, and athletes generally increase the stride length as much as possible to improve the speed, and the larger stride length forms a larger shoulder and hip torsion Angle.

In the run-up stage, the loss of the center of gravity speed obtained by the "324C+1D" action in the run-up direction in the take-off stage is mainly caused by the braking component impulse generated after the landing of the jumping foot, and the acceleration of the run-up speed increases the braking impulse accordingly. Therefore, the acceleration of the run-up speed increases the muscle load of the jumping leg during braking, so that the jumping leg exerts greater force on the ground, and then obtains greater ground reaction force, which is conducive to improving the push and stretch strength of the lower limbs and the jumping speed. On the other hand, the increase in the muscle load of the jumping leg often causes a corresponding increase in the centrifugal contraction force of the lower extremity extensor (concessional work). This phenomenon is conducive to converting the kinetic energy obtained in the run-up into the elastic potential energy of the muscle and storing it, and releasing it in the take-off and extension (centripetal contraction) action immediately afterwards, converting this potential energy into kinetic energy, and increasing the contraction force and contraction speed of the muscle in the process of mutual conversion of kinetic energy and potential energy. In addition, during the centrifugal contraction of the extensor muscle, the muscle spindle is stimulated to produce stretch reflex, which further strengthens the centrional contraction of the extensor muscle. Under the combined action of muscle elastic potential energy and stretch reflex, it is more conducive to increasing the push and stretch force of the lower limbs and shortening the jump time. Since the "324C+1D" action is to jump with both feet, the push and stretch strength is more sufficient, which makes up for the lack of the run-up speed, resulting in the "324C+1D" action is not high in the run-up speed.

It is worth noting that speeding up the run-up speed will also put forward higher requirements for the athletes' take-off braking ability. When the run-up speed exceeds the athletes' matching braking ability range, it will lead to the athletes' difficulty in grasping the best time to take off, resulting in insufficient take-off push and stretch, which will affect the take-off effect and the formation of the best take-off Angle. In addition, athletes may also dissipate more energy to control the center of gravity of the body in order to overcome the fast run-up speed, which will also affect the continuity of the action, lead to the extension of the jump time, restrict the play of the elastic potential energy of the lower limb muscle group, and affect the push and stretch strength and the jump effect. Therefore, in sports practice, the run-up speed is restricted by the special technical goal and the athlete's ability.

2. The impact of athletes' jumping on the "324C+1D" movement

There is no significant difference in biomechanical characteristics between the national athletes and the first-level athletes in the take-off stage of 324C+1D movements. The technical characteristics are mainly as follows: (1) The athletes have a large range of squat movements in the take-off stage. (2) The athlete's hip flexion is more obvious in the take-off, push and stretch stage. (3) The vertical movement distance of the center of gravity of the athlete in the take-off and push stage is not the larger the better or the smaller the better, but in a moderate range. (4) After the vertical speed of the center of gravity of the athlete reaches a higher level in the take-off and push and stretch stage, the fluctuation in a small range is not the key to affecting the athlete's completion of the movement. (5) Increasing the vertical reaction force of the ground in the take-off, push and stretch stage is conducive to the completion of the movement of the athletes on the one hand; On the other hand, when the vertical reaction force of the ground reaches a high value, a slight increase or decrease in a small range does not affect the athlete's completion of the movement. (6) The speed of the center of gravity is small and the Angle of center of gravity is greater than 70° in the run-up direction of the athlete at the time of pedalling and stretching off the ground.

According to the law of momentum, in order to obtain a larger initial velocity, the working distance of the force should be extended as far as possible while ensuring the maximum strength of the muscle. When the working distance reaches the maximum, the working distance should be completed in the shortest time to obtain the maximum speed (Lu, 2010) . The centrifugal contraction of lower limb extensor muscle before take-off, for the centripetal contraction of take-off, take-off and extension stage, is to increase the initial length before contraction, extend the work distance and force time of take-off and extension stage, which is conducive to increasing the push and extension force of lower limb extensor muscle and take-off speed. However, according to the relationship between initial length and muscle contraction force, the muscle contraction force increases in a certain range with the increase of initial length. When the initial length increases to a certain extent, the muscle contraction force reaches the maximum, and then the continuous increase of initial length will cause the decline of muscle contraction force (Wang, 2007) . Therefore, the ankle joint and the knee joint are not squatting as low as possible, but in a moderate joint Angle range, by increasing the muscle contraction force and accelerating the push and stretch speed, in order to achieve the best jumping effect. Aggravation of right hip flexion at the moment of departure when the athlete completes the "324C+1D" movement; To a certain extent, the vertical height of the center of gravity at the time of leaving the ground is reduced, which is conducive to increasing the vertical movement distance of the center of gravity at the stage of lifting. In addition, hip flexion when off the ground is beneficial to reduce the swing amplitude and shorten the swing time after lifting.

"324C+1D" action In the process of rapid squatting, the lower limb extensor muscles perform rapid centrifugal contraction, the elastic potential energy of the muscle is stored in this process, and is released in the subsequent push and stretch (centrional contraction), the potential energy is converted into kinetic energy, which is conducive to increasing the centrional contraction force and contraction speed of the muscle. At the same time of centrifugal contraction of the extensor muscle, the muscle spindle is stimulated to produce stretch reflex, which further strengthens the subsequent centripetal contraction of the extensor muscle. Under the combined action of muscle elastic potential energy and stretch reflex, it is more conducive to increasing the push and stretch force of the lower limbs and shortening the push and stretch time. In addition, the play of muscle elastic potential energy is affected by the speed of the "elongation-shortening" cycle, and the slower speed will lead to the decrease of tension and relaxation in the process of muscle elongation, and reduce the elastic retraction force during centripetal contraction. Therefore, speeding up the jumping speed, improving the consistency of jumping squat and jumping push and stretch, and shortening the jumping time are conducive to the athletes to complete the "324C+1D" movement.

In the take-off stage, the joint fan Angle in the lower limb joint linkage process affects the vertical movement distance of the center of gravity and the vertical speed of the center of gravity. The joint flexion at the time of lift-off also offends the vertical rise speed of the center of gravity to a certain extent. Therefore, the vertical movement distance of the center of gravity and the vertical speed of the center of gravity in the take-off, push and stretch stage also show that the larger the better or the smaller the better. It's in a moderate range. In addition, when the vertical speed of the center of gravity reaches a higher level, the athlete puts more energy into the rotation rather than the jump height in order to complete the "324C+1D" movement.

The technical requirements of "324C+1D" action in competitive martial arts routine competition determine the maximum demand for lifting distance and holding time in the air, and the speed of the center of gravity in different directions at the time of leaving the ground determines the lifting Angle of the center of gravity and the trajectory of the movement in the air. The gain of vertical speed is based on the loss of horizontal speed, and it is impossible to have a take-off technology with little horizontal speed loss and large vertical speed gain (Lu, 2010) . Therefore, the interaction between the loss of horizontal velocity and the gain of vertical velocity results in the formation of the lifting Angle of the center of gravity at the time of liftoff (Arthur E & Chapman, 2010) . From the perspective of "324C+1D" movement, the speed of the center of gravity in the run-up direction at the time of departure from the ground is small, and the lifting Angle is close to 90°, which determines that the center of gravity of the human body in the airborne stage of "324C+1D" movement is approximately straight up and down. According to the projectile formula (Tan, 2009) , If other conditions remain unchanged, the lifting Angle of the center of gravity at 90° can obtain the highest lifting height, so the "324C+1D" action should try to convert the run-up speed into the largest vertical speed as possible in the jumping stage.

3. Influence of torso rotation, arm swing and leg swing before takeoff on the "324C+1D" movement

The biomechanical characteristics of torso rotation, arm swing and leg swing before 324C+1D movement were not significantly different between national athletes and first-level athletes, which were mainly shown as follows: (1) Appropriate increase of the shoulder-hip torsion Angle before 324C+1D movement and the shoulder-foot torsion Angle at the time of liftoff was conducive to the athlete's completion of the movement. (2) The peak arm swing speed of "324C+1D" movement in the jumping stage is larger.

To a certain extent, the reverse rotation amplitude of the trunk and the reverse swing amplitude of the arm before the take-off and push out can make the rotator muscle group of the trunk and the swing muscle group of the arm centrifugal and elongate, which is beneficial to store more muscle elastic potential energy and release it in the subsequent reverse acceleration movement, converting the potential energy into kinetic energy and increasing the centripetal contraction force of the muscle. In addition, the centrifugal elongation of trunk rotator muscle group and arm swing muscle group increases the initial length of muscle before centripetal contraction, increases the work distance of muscle centripetal contraction, and prolongs the action time, which is conducive to the increase of impulse moment and the rotation speed of swing arm and trunk. The shoulder and foot torsion Angle at the moment of departure from the ground is the result of the rotation of the torso before takeoff. The increase of the Angle reduces the rotation Angle needed to complete after takeoff to a certain extent. Therefore, athletes usually maximize the shoulder and foot torsion Angle before takeoff in difficult movements.

In the "324C+1D" movement, the athlete's arm presents an accelerated arc swing from the bottom to the top, and the arm swing speed increases with the difficulty level. According to Newton's laws of mechanics, the swinging arm movement produces opposite and equal reaction force, which is transmitted through other connecting parts of the body and acts on the jumping leg. While increasing the load of the jumping leg, it also increases the pushing force of the jumping leg against the ground, thus obtaining greater ground reaction force. When the swing arm and leg speed reach the maximum, the upward swing arm and leg motion quickly decelerate and brake. Under the upward inertia trend, the muscle load of the jumping leg is reduced, which is conducive to the lower limb overcoming its own gravity faster in the push and stretch stage, and the jumping speed is increased. According to Newton's laws of mechanics, "the reaction force of two objects is equal, in the opposite direction, along the same straight line, and respectively acts on two objects to produce their own effects," the most conducive to "jump high" swing arm, swing leg technology, should be the arm and left leg in front of the body quickly and powerfully from the bottom up, rather than from the bottom to the top of the arc swing. This shows that the swing of the arms and legs in the "324C+1D" movement is not only to "jump high" but also to be fully prepared for "turn fast".

According to the law of conservation of moment of momentum, the condition of conservation of moment of momentum is satisfied when the human body is in a state of unsupported vacation (Lu, 2010) . Therefore, in order to complete the turning action in the air, it is necessary to obtain the moment of momentum (angular momentum) to make the body rotate in the state of jumping support (Arthur E & Chapman, 2010) [100]. When the athlete completes the "324C+1D" action, in the support state before flying, he obtains a moment of momentum (angular momentum) that makes the body rotate around the vertical axis through the movement of the torso, the swing arm and the swing leg. If he wants to increase the angular momentum before flying, according to the relationship among angular momentum, angular velocity and moment of inertia, Athletes in the jumping support state of the swing arm, swing leg movement trajectory should be as close to the horizontal plane as possible, extend the elbow, straight knee swing, so that the swinging body as far as possible away from the trunk, increase the moment of inertia, and increase the muscle strength to speed up the swing arm, swing leg speed, in order to obtain greater angular momentum.

It is worth noting that: (1) In the reverse movement of the turn and swing arm, it is necessary to strengthen the coherence of the action, shorten the transition time from muscle extension to contraction as much as possible, maximize the use of the elastic potential energy of the muscle, and increase the centripetal contraction force of the muscle. (2) It is necessary to take into account the best range of the reverse movement. According to the relationship between the initial length and the strength curve, the increase of the initial length is not the greater the better. When the muscle strength reaches the maximum with the increase of the initial length, the further increase of the initial length will cause the muscle strength to decline; In addition, the rotation and swing arm action should be combined with the push and stretch jumping action, and the pursuit of increasing the work distance of the rotation and swing arm and extending the action time will inevitably affect the jumping speed and jumping time. Therefore, the best turning and swinging arm program is to speed up the take-off speed and shorten the take-off time, while ensuring a certain pre-stretching amplitude, speeding up the turning and swinging arm speed, so as to obtain a larger initial speed and angular momentum of the turning body, creating favorable conditions for the completion of the "324C+1D" movement of the airborne turning movement. (3) According to the relationship between angular momentum and moment of inertia, moment of inertia and axis distance, and action and reaction force, the motion trajectory of swing arm and leg in the take-off stage regulates the contradictory technical action task of "jumping higher" or "turning faster" to a certain extent, and takes both into account to a certain extent. It reflects the ability of high-level athletes to control the Angle of limb swing.

4. Impact of air attitude change on the movement of "324C+1D"

When the human body is in the air, the moment of momentum is conserved, and the human body is only subject to the action of gravity, and the internal force of the human body can only produce the relative motion of the body links, and cannot change the movement trajectory of the whole body's center of gravity (Arthur E & Chapman, 2010) . However, the human body can change the moment of inertia with the help of changes in air posture and relative movement of links, so as to realize the transfer of the moment of momentum between basic axes and the change of the rotational speed of the body (Lu, 2010) .

"324C+1D" movement in the air stage mainly includes: swing leg stroke, swing leg pressure, bending arms to chest, turning head and twisting waist, and leg rotation, arm spread leg and other changes in air posture. The main technical characteristics of these air movements are as follows: (1) the athlete has a certain angular rotational speed of the shoulder shaft at the moment of hitting when completing the "324C+1D" movement in the air stage; after hitting, the angular rotational speed of the shoulder shaft increases to the peak level, and the angular rotational speed of the shoulder shaft decreases, and a certain angular rotational speed of the shoulder shaft is maintained at the moment of landing. (2) The vertical height of the center of gravity at the moment when the athlete completes the "324C+1D" movement is greater than the vertical height of the center of gravity at the moment of landing, so the vertical movement distance of the center of gravity rising is less than the vertical movement distance of the center of gravity falling.

From the perspective of the influence of the change of body posture on the moment of inertia and angular velocity, in the stage from the ground to the beating action, the right leg and left hand are far away from the trunk due to the arc swing of the right leg and the extended arm of the left hand, resulting in the increase of moment of inertia and the slow angular velocity of the trunk around the vertical axis. After the stroke, the right leg is accelerated to press down and close to the left leg, while the two arms bend the elbow to the chest, so that the body is close to the trunk, and the rotation radius of the limb around the vertical axis is shortened in the process of this movement, resulting in the reduction of the moment of inertia, and the angular speed of the trunk around the vertical axis is accelerated. Therefore, speeding up the swing speed of the right leg before the stroke is conducive to shortening the time of the action stage with the increase of the moment of inertia, and reserving more time for the action stage with the small moment of inertia after the stroke, which is conducive to the athlete completing a larger rotation Angle in the air stage.

In the process of center of gravity fall, in order to connect the horse step action after landing, the two legs need to be separated before landing, so that the distance between the two feet is increased, usually accompanied by a slight extension of the two arms and elbow extension. On the one hand, this is conducive to creating favorable conditions for the support of the horse after landing; On the other hand, leg splitting and arm spreading move the limbs away from the torso, resulting in increased moment of inertia and slower rotation speed, which is conducive to reducing the rotational inertia after landing. Of course, this attitude change is in the trunk speed and stagnation time to ensure that the athlete can complete the required rotation Angle, if the speed or stagnation time is insufficient, the athlete will try to maintain the bending arm chest, and leg rotation (rotation speed is faster) in the center of gravity drop stage in order to complete the larger rotation Angle, and delay the action time of leg splitting. In addition, it will delay the time of foot landing by increasing the flexion of the hip, knee and ankle joints to achieve the purpose of increasing the falling distance and holding time, which will lead to problems such as the vertical center of gravity at the time of landing, the trunk speed is too fast, and the distance between the two feet is too small.

It is worth noting that the change of body posture in the air should minimize the excess shaking of the torso caused by the relative movement of the body link to avoid adverse effects on the smooth rotation of the body. In addition, from the perspective of the trunk shape in the air stage, in the process of completing the air movement, try to make the trunk and the rotating axis, that is, the trunk is close to the vertical axis, in order to shorten the rotation radius, reduce the moment of inertia, and increase the angular speed of the air rotation, which is not only conducive to the athletes in the air stage to complete a greater degree of rotation, but also to improve the completion quality of the air movement.

5. Impact of Landing connection on the "324C+1D" movement

There is no significant difference in biomechanical characteristics between national athletes and first-level athletes when completing 324C+1D "movements, mainly as follows: (1) the shoulder-foot torsion Angle is well controlled at the landing moment; second-level athletes can avoid excessive shoulder-foot torsion Angle at the landing moment through other compensatory mechanisms when completing" 324C+1D "movements. (2) Athletes in the landing stage usually left knee joint fan Angle is larger than the right knee joint fan Angle. (3) When the completion difficulty is within a certain range, the athlete may buffer the impact force after landing by increasing the vertical movement distance of the center of gravity in the landing buffer stage, but when the difficulty exceeds this range of ability, the vertical movement distance of the center of gravity will be reduced. (4) When athletes complete the "324C+1D" movement, they may still bear a large ground reaction force in the landing buffer stage. The reason is that athletes actively reduce the cushioning effect of lower limb centrifugal contraction in order to achieve the perfect technical requirements of "rapid stability" at the moment of landing.

The main technical purpose and task of the landing stage is to ensure the stability of the landing connection. According to the relevant theories of sports biomechanics, the stability of the human body is mainly affected by the following factors: the size of the support surface, the height of the center of gravity, the stability Angle and the stability coefficient. In addition, the stability of the jumping action during the landing stage is also affected by the impact force and muscle braking ability after landing. The leg splitting action before landing determines the distance between the two feet after landing. The size of the supporting area composed of the distance between the two feet affects the stability of the athlete's action after landing to a certain extent. Generally speaking, the supporting surface is large and the stability is large, while the supporting surface is small and the stability is small.

Usually in sports practice, when the difficulty reaches or approaches a certain ability threshold of the athlete, the continued increase of the rotation Angle will be restricted by the rotation speed, air height and air retention time. In order to complete the rotation task with a larger Angle, on the one hand, the athlete will try to maintain the body posture with a faster rotation Angle (with legs and elbows attached to the chest) for a longer time. However, delaying the action time of leg splitting and arm extension leads to insufficient leg and arm extension action at the time of landing, resulting in problems such as too small distance between the two feet after landing, too fast rotation angular speed and too large shoulder and foot twisting Angle, which not only reduces the stability coefficient, but also increases the difficulty of rotary braking after landing. On the other hand, athletes will increase the curvature of the lower limb joints before landing, reduce the vertical height of the center of gravity at the moment of landing, delay the landing time of the supporting foot, and extend the moving distance and stagnation time of the center of gravity falling vertically. Due to the increase of the moving distance of the center of gravity falling, the action time of gravitational acceleration will be prolonged, and the vertical speed of the center of gravity at the moment of landing will also increase. In addition, reducing the vertical height of the center of gravity at the moment of landing will crowd out the landing buffer distance to a certain extent, and the landing buffer action completed in this state will inevitably lead to the horse step action closer to the squat state, which increases the difficulty of the centrifugal braking of the lower limb extensor muscle, and it is easy to make the horse step action into a wrong posture with a small distance between the feet and a low body center of gravity. The action quality of landing connection is seriously affected.

It is worth noting that: (1) According to Newton's third law, "when two objects interact, the force of object A on object B is equal to the reaction force of object B on object A, in the opposite direction, along the same straight line, and each acts on the two objects to produce their own effects." In the landing buffer stage, the first-level athletes need to overcome slightly different impact forces when completing the "324C+1D" action, and the movement trajectory in the air is close to straight up and down. (2) The left knee joint fan Angle of "324C+1D" movement in the landing buffer stage is generally larger than that of the right knee joint fan Angle. The reasons are due to special technical characteristics, individual habits of athletes and the difference of braking ability of left and right legs. However, in the buffering process, the difference in the Angle of the left and right limbs joint fan may lead to the deviation of the body gravity action line in the support plane. If the deviation is too large, the gravity action line will be close to the boundary of the support plane or even exceed the boundary of the support plane, which will lead to the failure of the landing connection. Therefore, in the process of landing buffer, we should pay attention to the control of the center of gravity of the body.

Practical Implications

(1) This paper analyzes and summarizes the biomechanical characteristics of national wushu routine athletes completing "324C+1D" movements, and discusses the biomechanical characteristics of national Wushu routine athletes completing "324C+1D" movements by using the theory of sports biomechanics.

(2) This paper analyzes and summarizes the biomechanical characteristics of the "324C+1D" movement of the first-level wushu routine athletes, and discusses the biomechanical characteristics of the "324C+1D" movement of the first-level Wushu routine athletes by using the theory of sports biomechanics.

(3) Compared and analyzed and summarized the biomechanical characteristics of national Wushu routine athletes and first-level Wushu routine athletes completing "324C+1D" movements, and discussed the biomechanical characteristics of national Wushu routine athletes and first-level Wushu routine athletes completing "324C+1D" movements by using the theory of sports biomechanics.

Shortcomings of this study and prospects for further research

(1) Since this study is aimed at difficult and complex technical movements, which has high requirements for three-dimensional force measuring tables and wireless surface electromyograph, the special technical movement test was conducted under laboratory conditions, and the relevant data indicators could not be obtained under competition conditions.

(2) Due to the small number of top competitive wushu routine athletes who can complete the "324C+1D" movement, only 6 male athletes participated in the test in this study, which were divided into two groups according to the sport level, 3 national athletes and 3 first-class athletes. Due to the limited sample size of each group, data analysis with a large sample size could not be performed. The biomechanical characteristics of "324C+1D" movement in athletes of different genders and different age groups have not been studied, which will be the follow-up research direction of this study.

Suggestion

(1) The lifting Angle of the center of gravity at the time of the athlete's take-off stage needs to be as close as possible to 90°; In the take-off stage, athletes need to increase the torsion Angle of shoulders and hips as much as possible, speed up the swing arm speed, increase the torsion Angle of shoulders and feet at the time of leaving the ground, speed up the squat speed in the vertical direction of the center of gravity, and shorten the take-off time in the squat and push and stretch stage.

(2) In the air stage, the athlete needs to increase the vertical speed of the center of gravity before the stroke, increase the vertical movement distance between the center of gravity lifting stage and the center of gravity falling stage, extend the air holding time, accelerate the swing speed of the right leg, move the moment of the stroke to the rapid rising period of the center of gravity lifting as far as possible, speed up the angular rotation speed of the shoulder shaft in the air stage, and increase the angular rotation speed of the shoulder shaft after the stroke. Strength training to strengthen the right leg pressing muscle group, the vertical spine muscle, the right leg abduction active muscle group and the right turn of the trunk active muscle group.

(3) Athletes should strengthen the training of abdominal external oblique muscle, vertical ridge muscle and leg strength in muscle strength training, especially the strength training of the left leg, which is conducive to improving the stability of the athletes to complete the movement.

Conclusions

(1) The factors affecting the lifting distance of the "324C+1D" action are: Speed of run-up and take-off, center of gravity lifting Angle, ground reaction force during take-off push and extension, center of gravity height at the time of leaving the ground, Angle and speed of swinging arms and legs before lifting, etc., the lifting distance in the air is the basis and premise for athletes to complete difficult actions, and when reaching a certain range, it is not the key to the completion of "324C+1D" action.

(2) The factors that affect the rotation Angle of "324C+1D" movement are: the Angle and speed of swinging arms and legs before flying, the twisting Angle of shoulders and feet when leaving the ground and landing, the falling distance in the air, the speed of swinging legs in the air and the control of body posture, etc. Rotation Angle is the key for athletes to complete difficult movements.

(3) The factors affecting the landing connection of "324C+1D" action are: landing buffer distance, landing shoulder and foot torsion Angle, landing ground reaction force, etc.

(4) There is no significant difference between the sports biomechanical characteristics of national athletes and first-class athletes in completing "324C+1D" movements.

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APPENDIX

Appendix A

Ethic Certificate

MAHASARAKHAM UNIVERSITY ETHICS COMMITTEE FOR
RESEARCH INVOLVING HUMAN SUBJECTS

Certificate of Approval

Approval number: 510-344/2023

Title : Biomechanical Characteristics Analysis of Highly Difficult Movements "324C+1D" in Competitive Wushu Routine.

Principal Investigator : Xikui Guo
Responsible Department : Faculty of Education
Research site : Ankang city, Shaanxi province, China

Review Method : Expedited Review

Date of Manufacture : 30 November 2023 **expire :** 29 November 2024

This research application has been reviewed and approved by the Ethics Committee for Research Involving Human Subjects, Mahasarakham University, Thailand. Approval is dependent on local ethical approval having been received. Any subsequent changes to the consent form must be re-submitted to the Committee.

Ratree S.
(Asst. Prof. Ratree Sawangjit)
Chairman

Approval is granted subject to the following conditions: (see back of this Certificate)

ECMSU01-09.03 Update 2021

Clarification documents for the volunteers who Experiment

Dear all Subject

Because I (Xikui Guo, PhD candidate, Health and Sport Science. Educational Faculty, Mahasarakham University) conducting research on "Biomechanical Characteristics Analysis of Highly Difficult Movements '324C+1D' in Competitive Wushu Routine". You may not benefit directly from participating in this research project. However, the findings of this project may support the training decisions of your coaching team, help improve the efficiency of you and your teammates in the training of similar difficulty movements, and improve the success rate of completing similar difficulty movements.

After being recommended by your coach and interviewed by the researcher, you are eligible to be a volunteer for this study. If you decide to participate in this study, you will be asked to provide your basic personal information. If you feel uncomfortable or uncomfortable with certain questions, you have the right not to answer them.

You and 5 other athletes will participate in a sports biomechanics test project, the test requirements and details are as follows: (1) Topless, wearing tight shorts provided by the researcher, wearing your usual training and competition sports shoes. (2) During the test, you will need to apply an EMG patch and install a wireless EMG test device on the skin surface of your vertical spinal muscles, external oblique abdominal muscles, gluteus maximus, biceps femoris, rectus femoris and gastrocnemius muscles. When applying the skin patch, it is necessary to remove hair from the skin and wipe with alcohol. Emg patches and wireless EMG devices are mainly used to collect the surface EMG value of muscles, which will not cause harm to health. (3) Complete the run-up, jump and landing of the "324C+1D" movement in the designated area, and judge the success and failure of the movement according to the opinion of the referee on the scene. Each person is required to successfully complete 3 times, and the test can be repeated if there is a failure to complete the movement during the test. (4) Follow the instructions of field staff to complete the test during the test.

You also have the right to withdraw from the program at any time without prior notice. And not participating in or withdrawing from the research project will not affect you in any way. Your Basic personal information will be retained and not disclosed to the public. Your Basic personal information will only be used for this study, and the relevant data will be destroyed after the study is completed. All participants' data will be encrypted and stored on the researcher's computer. Set the password for the folder where the data is saved, and set the computer boot password. After the end of the experiment, all the experimental data on the experimental instrument will be deleted to ensure that the experimental data will not be leaked during the collection process. The analysis and digitization of the experimental data is carried out on the researchers' computers to ensure that there is no risk of data leakage. We will only use comprehensive information and data for reporting and will not disclose personal information of volunteers. You will not be paid or charged for the study.

If you have questions about the research Please feel free to contact us at (Xikui Guo- Health and Sport Science. Educational Faculty, Mahasarakham University, Phone: +861599[illegible]). If you were not treated as described or want to know your rights while participating in this study, You can contact at "Human Research Ethics Committee Mahasarakham University Division of Research and Academic Service Promotion Mahasarakham University "Tel. +6643-754416 Internal number 1755

Sincerely

....

(Xikui Guo)

Researcher

ECMSU01-07.10 English 2023

Study informed consent from the volunteer head coach

I (Mr.) .... Surname .... Age.............Year.
House number .... Village No. .... Sub-district .... District ....
province....................................
Convenient phone ....

Read the explanation / listen to the explanation from Mr. Xikui Guo about volunteering in the research project on "Biomechanical Characteristics Analysis of Highly Difficult Movements '324C+1D' in Competitive Wushu Routine", the explanatory text consists of Full details about the purpose of the research, details of the research. I agree with the value of the study, I am aware of the benefits to be gained and the risks that may arise from participating in the study. Include guidelines for possible problems. Explanations and answers to any questions from the head of the research project were also received.

The researcher promised to keep confidential information about my martial arts team. In addition, anonymous or private information may not be made available to the public alone. The findings will be presented in the form of an overview, which is a summary of the findings for academic purposes only.

"As the volunteer's referrer and coach, I gave them permission to participate in the study." I agree that my recommended volunteers can withdraw from the study at any time. This will have no impact and will not result in the loss of any right to study or work in the future.

sign... Head coach
(............Mr.Hailang Zhang..........)
Date...

sign... researcher
(Mr.Xikui Guo)
Date..

มหาวิทยาลัยมหาสารคาม
Mahasarakham University
Ethics Committee for Human Research
คณะกรรมการจริยธรรมการวิจัยในคน

ECMSU01-07.10 English 2023

Informed consent form for research from volunteers
(For volunteers over 18 years old)

I (Mr.) .... Surname .... Age.............Year.
House number .... Village No. .... Sub-district .... District ....
province....................................
Convenient phone ....

Read the explanation / listen to the explanation from Mr. Xikui Guo about volunteering in the research project on "Biomechanical Characteristics Analysis of Highly Difficult Movements '324C+1D' in Competitive Wushu Routine", the explanatory text consists of Full details about the purpose of the research, details of the research. That I have to do and be treated, the benefits that I may gain from the research and the risks that may arise from participating in the study. Including guidelines for questions that may arise throughout. It has also received an explanation and an answer to any questions from the research project leader.

As well as the testimony from the researcher that will keep my information confidential. In addition, not anonymously or private information individually to the public. The results of the research will be presented in the form of an overview that is a summary of the research results for academic purposes only.

"In participating as a volunteer of this research project I join voluntarily." And I can withdraw from this study at any time. If I wish which will not have any effect and will not lose any rights in study or work that I will receive in the future.

sign.. Volunteers
(...)
Date..

sign... witness
(...........Mr.Hailang Zhang............)
Date..

sign... researcher
(Mr.Xikui Guo)
Date..

Experimental instruments and procedures

1 Test Instrument

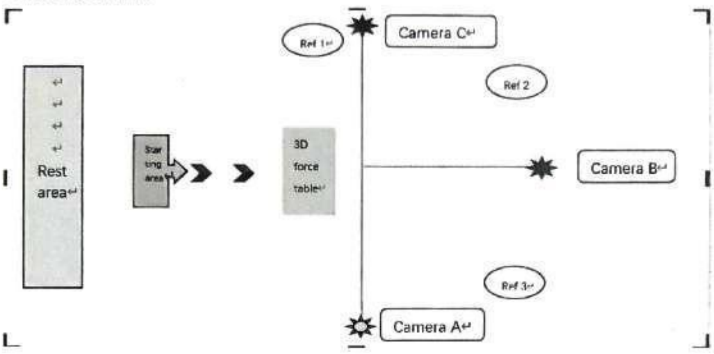
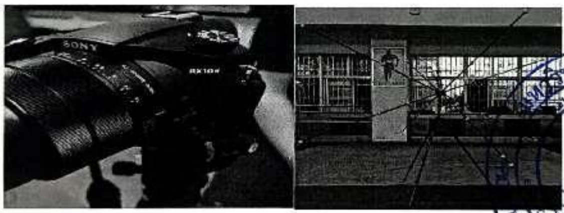


Figure 1 Test site layout diagram

1.1 3D High-speed camera system



Three Japanese SONY-RX10IV cameras, a set of SIMI Motion software of SIMI company, calibration frame using Agger 3D DTL framework calibration. 3D high-speed camera system can be used in the study of human movement, which can truly reproduce the movement and movement trajectory of athletes, and output the movement data of each link of athletes at any time, such as displacement, speed, angular speed, etc., so as to facilitate quantitative analysis. Combined with the principles of human physiology and physics, the research and improvement methods can make the observation of human movement get rid of the state of relying purely on experience. Enter the theoretical digital era, 3D high-speed camera is a non-contact measurement, which has the advantages of not imposing extra load on the human body, not interfering with the body movement and measuring close to the actual condition. The detection and processing of human motion information takes human motion as the research object. Measure and analyze the displacement, velocity, acceleration and joint Angle of

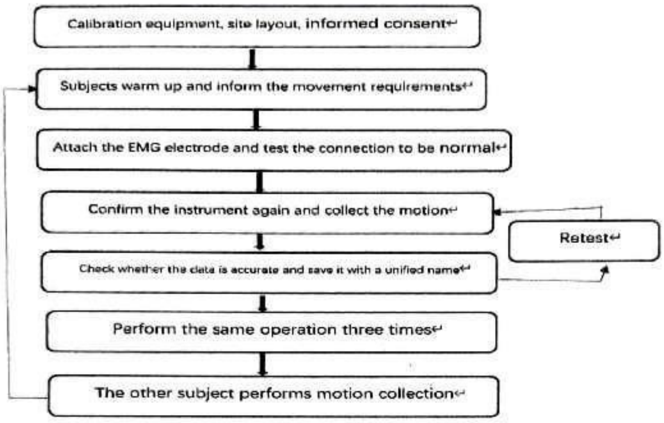


Figure 2 Test flow chart

3.3 Precautions

3.3.1 The guarantee of exercise safety of test participants

Ensure that subjects are fully aware of the test requirements and procedures, and ensure that a thletes are fully warmed up before the test to avoid sports injuries. Invite a doctor to take a medical kit to the test. If the participant has a sports injury during the test, the doctor can provide medical services to the participant in time.

3.3.2 Safety assurance of experimental instrument operation

The test equipment is operated by professional operators to ensure the accuracy of the experimental data collection and the safety of the instrument.

3.3.3 Security assurance of test data

After the test, the test data will be saved to the researcher's special computer to ensure the safety of the test data.

value, minimum value, root mean square amplitude (RMS), integrated electromyography (IEMG), power spectrum (PSD), and customized analysis. The wireless electromyography test system can obtain data such as the order of muscle work done and the amount of work done when athletes perform difficult movements without affecting their performance. Through data analysis, the surface EMG characteristics of athletes performing the technical movements can be obtained.

In addition to the professional equipment for sports biomechanics testing, we also need to use some common tools, such as laptops, during the testing process. Two computers, including SIMI 3D motion image analysis system, 3D force measuring table data analysis software, electromyography data analysis system, electromyography and force measuring table synchronization system, and an external synchronizer are installed.

2 Test Time and test location

Test site: Sports biomechanics Laboratory, Xi 'an Sports University.

Test time: Test preparation (late May 2023), formal test (early September 2023).

3 Test procedure and precautions

3.1 Preparing for Tests

According to the problems found in the test preparation, eliminate all the hidden dangers that may affect the accuracy of the test, install and debug the equipment and make preparation for the test. All subjects were asked to bare the upper half of their bodies, wear high-stretch tight shorts, and wear their usual training sneakers. All subjects were numbered and recorded before the test began.

Warm-up activities were performed before the test began, and EMG electrodes were applied after full warm-up.

Electrode paste personnel, test athletes to maintain neutral, along the longitudinal axis of the muscle in the muscle belly of the most prominent position with double-sided adhesive tape, fixed with elastic bandage, then put on tights, to prevent the electrode slip or fall off during movement.

Take the right leg of the lower limb as an example (the vastus lateralis, rectus femoris, vastus medialis, tibialis anterior, gastrocnemius, gluteus maximus, in order). Open the electrodes attached to the test athlete. Verify that the computer can connect to the electrode and perform signal detection.

3.2 Test Process

The athletes completed three times of 324C+1D movement in the sequence of numbering.

Three first-level judges were invited to evaluate the completion of movements at the test site, and the one with complete kinematic data collection and the highest movement quality was selected for data preservation. After the first subject finishes the test and saves the test data, the second subject starts the test and completes the test of all subjects in turn and keeps the test data properly. Arrange and return the test instrument as soon as possible after the test.

Appendix B

Documents signed by the subjects

ECMSU01-09.03 Update 2021

Clarification documents for the volunteers who Experiment

Dear all Subject

Because I (Xikui Guo, PhD candidate, Health and Sport Science. Educational Faculty, Mahasarakham University) conducting research on "Biomechanical Characteristics Analysis of Highly Difficult Movements '324C+1D' in Competitive Wushu Routine". You may not benefit directly from participating in this research project. However, the findings of this project may support the training decisions of your coaching team, help improve the efficiency of you and your teammates in the training of similar difficulty movements, and improve the success rate of completing similar difficulty movements.

After being recommended by your coach and interviewed by the researcher, you are eligible to be a volunteer for this study. If you decide to participate in this study, you will be asked to provide your basic personal information. If you feel uncomfortable or uncomfortable with certain questions, you have the right not to answer them.

You and 5 other athletes will participate in a sports biomechanics test project, the test requirements and details are as follows: (1) Topless, wearing tight shorts provided by the researcher, wearing your usual training and competition sports shoes. (2) During the test, you will need to apply an EMG patch and install a wireless EMG test device on the skin surface of your vertical spinal muscles, external oblique abdominal muscles, gluteus maximus, biceps femoris, rectus femoris and gastrocnemius muscles. When applying the skin patch, it is necessary to remove hair from the skin and wipe with alcohol. Emg patches and wireless EMG devices are mainly used to collect the surface EMG value of muscles, which will not cause harm to health. (3) Complete the run-up, jump and landing of the "324C+1D" movement in the designated area, and judge the success and failure of the movement according to the opinion of the referee on the scene. Each person is required to successfully complete 3 times, and the test can be repeated if there is a failure to complete the movement during the test. (4) Follow the instructions of field staff to complete the test during the test.

You also have the right to withdraw from the program at any time without prior notice. And not participating in or withdrawing from the research project will not affect you in any way. Your Basic personal information will be retained and not disclosed to the public. Your Basic personal information will only be used for this study, and the relevant data will be destroyed after the study is completed. All participants' data will be encrypted and stored on the researcher's computer. Set the password for the folder where the data is saved, and set the computer boot password. After the end of the experiment, all the experimental data on the experimental instrument will be deleted to ensure that the experimental data will not be leaked during the collection process. The analysis and digitization of the experimental data is carried out on the researchers' computers to ensure that there is no risk of data leakage. We will only use comprehensive information and data for reporting and will not disclose personal information of volunteers. You will not be paid or charged for the study.

If you have questions about the research Please feel free to contact us at (Xikui Guo- Health and Sport Science. Educational Faculty, Mahasarakham University, Phone: +8615991486663). If you were not treated as described or want to know your rights while participating in this study, You can contact at "Human Research Ethics Committee Mahasarakham University Division of Research and Academic Service Promotion Mahasarakham University "Tel. 043-754416 Internal number 1755

Sincerely

......Xi Kui Guo

(Xikui Guo)

Researcher

ECMSU01-07.10 English 2023

Study informed consent from the volunteer head coach

I (Mr.) ....Hai Lang.................. Surname ..Zhang.................. Age.1986.Year.
House number 2412..... Village No. ....\.... Sub-district Zhang ba gou. District ..Yan ta.............
province...Shaan xi..............
Convenient phone ....158 29 21 8697..................

Read the explanation / listen to the explanation from Mr. Xikui Guo about volunteering in the research project on "Biomechanical Characteristics Analysis of Highly Difficult Movements '324C+1D' in Competitive Wushu Routine", the explanatory text consists of Full details about the purpose of the research, details of the research. I agree with the value of the study, I am aware of the benefits to be gained and the risks that may arise from participating in the study. Include guidelines for possible problems. Explanations and answers to any questions from the head of the research project were also received.

The researcher promised to keep confidential information about my martial arts team. In addition, anonymous or private information may not be made available to the public alone. The findings will be presented in the form of an overview, which is a summary of the findings for academic purposes only.

"As the volunteer's referrer and coach, I gave them permission to participate in the study." I agree that my recommended volunteers can withdraw from the study at any time. This will have no impact and will not result in the loss of any right to study or work in the future.

sign...........Hailang Zhang........... Head coach
(............Mr.Hailang Zhang..........)
Date...........01 . 12 . 2023..............

sign................Xikui Guo............ researcher
(Mr.Xikui Guo)
Date..........01 . 12 . 2023..................

ECMSU01-07.10 English 2023

Informed consent form for research from volunteers
(For volunteers over 18 years old)

I (Mr.) ......Yu Liang..................... Surname ....Li........................ Age..2004..Year.
House number ...6-207 Village No. ...\...... Sub-district Zhang ba gou... District ...Yan ta.............
province..Shaan Xi...........
Convenient phone ....13292395352 ....

Read the explanation / listen to the explanation from Mr. Xikui Guo about volunteering in the research project on "Biomechanical Characteristics Analysis of Highly Difficult Movements '324C+1D' in Competitive Wushu Routine", the explanatory text consists of Full details about the purpose of the research, details of the research. That I have to do and be treated, the benefits that I may gain from the research and the risks that may arise from participating in the study. Including guidelines for questions that may arise throughout. It has also received an explanation and an answer to any questions from the research project leader.

As well as the testimony from the researcher that will keep my information confidential. In addition, not anonymously or private information individually to the public. The results of the research will be presented in the form of an overview that is a summary of the research results for academic purposes only.

"In participating as a volunteer of this research project I join voluntarily." And I can withdraw from this study at any time. If I wish which will not have any effect and will not lose any rights in study or work that I will receive in the future.

sign...........Yu Liang Li............. Volunteers
(............Mr. Yuliang Li.........................)
Date...........01.12.2023..................

sign..............Hailang Zhang........ witness
(...........Mr.Hailang Zhang............)
Date.............01.12.2023.........

sign..............Xi Kui Guo......... researcher
(Mr.Xikui Guo)
Date..............01.12.2023............

ECMSU01-07.10 English 2023

Informed consent form for research from volunteers
(For volunteers over 18 years old)

I (Mr.) ....Yang.............................. Surname ..Xiang.................. Age.2002..Year.
House number 6-203.. Village No. ...\...... Sub-district Zhang ba gou... District ....Yan ta...........
province..Shaan Xi.............
Convenient phone .....18292395352.... ....

Read the explanation / listen to the explanation from Mr. Xikui Guo about volunteering in the research project on "Biomechanical Characteristics Analysis of Highly Difficult Movements '324C+1D' in Competitive Wushu Routine", the explanatory text consists of Full details about the purpose of the research, details of the research. That I have to do and be treated, the benefits that I may gain from the research and the risks that may arise from participating in the study. Including guidelines for questions that may arise throughout. It has also received an explanation and an answer to any questions from the research project leader.

As well as the testimony from the researcher that will keep my information confidential. In addition, not anonymously or private information individually to the public. The results of the research will be presented in the form of an overview that is a summary of the research results for academic purposes only.

"In participating as a volunteer of this research project I join voluntarily." And I can withdraw from this study at any time. If I wish which will not have any effect and will not lose any rights in study or work that I will receive in the future.

sign.........Yang Xiang.......... Volunteers
(.......Mr. Yang Xiang..........................)
Date.........01.12.2023...............

sign..............Hai lang Zhang..... witness
(...........Mr.Hailang Zhang............)
Date............01.12.2023...........

sign..............Xi kui Guo....... researcher
(Mr.Xikui Guo)
Date.............01.12.2023.........

ECMSU01-07.10 English 2023

Informed consent form for research from volunteers
(For volunteers over 18 years old)

I (Mr.) ....Jia Le.......................... Surname ..Zhu........................ Age.2004.Year.
House number .6-205. Village No. ....\..... Sub-district Zhang.ba.gou.. District ...Yan.ta............
province..Shaan..Xi............
Convenient phone ......18292239.5352. ....

Read the explanation / listen to the explanation from Mr. Xikui Guo about volunteering in the research project on "Biomechanical Characteristics Analysis of Highly Difficult Movements '324C+1D' in Competitive Wushu Routine", the explanatory text consists of Full details about the purpose of the research, details of the research. That I have to do and be treated, the benefits that I may gain from the research and the risks that may arise from participating in the study. Including guidelines for questions that may arise throughout. It has also received an explanation and an answer to any questions from the research project leader.

As well as the testimony from the researcher that will keep my information confidential. In addition, not anonymously or private information individually to the public. The results of the research will be presented in the form of an overview that is a summary of the research results for academic purposes only.

"In participating as a volunteer of this research project I join voluntarily." And I can withdraw from this study at any time. If I wish which will not have any effect and will not lose any rights in study or work that I will receive in the future.

sign.........Jia Le Zhu.......... Volunteers
(.....Mr. Jiale Zhu..............................)
Date..........01.12.2023..................

sign............Hailang Zhang...... witness
(..........Mr.Hailang Zhang...........)
Date..........01.12.2023...............

sign..............Xi Kui Guo......... researcher
(Mr.Xikui Guo)
Date............01.12.2023..........

ECMSU01-07.10 English 2023

Informed consent form for research from volunteers
(For volunteers over 18 years old)

I (Mr.) ...Wen Long.................. Surname ......Li........................ Age 2001..Year
House number 9-507 Village No. ...\.... Sub-district Zhang ba Gou.. District ...Yan ta...........
province..Shaan Xi.............
Convenient phone ....198 9093 0924.. ....

Read the explanation / listen to the explanation from Mr. Xikui Guo about volunteering in the research project on "Biomechanical Characteristics Analysis of Highly Difficult Movements '324C+1D' in Competitive Wushu Routine", the explanatory text consists of Full details about the purpose of the research, details of the research. That I have to do and be treated, the benefits that I may gain from the research and the risks that may arise from participating in the study. Including guidelines for questions that may arise throughout. It has also received an explanation and an answer to any questions from the research project leader.

As well as the testimony from the researcher that will keep my information confidential. In addition, not anonymously or private information individually to the public. The results of the research will be presented in the form of an overview that is a summary of the research results for academic purposes only.

"In participating as a volunteer of this research project I join voluntarily." And I can withdraw from this study at any time. If I wish which will not have any effect and will not lose any rights in study or work that I will receive in the future.

sign.........Wen Long Li.................... Volunteers
(.....Mr. Wen Long Li..........................)
Date........01 . 12 . 2023.....................

sign...............Hai lang Zhang..... witness
(...........Mr.Hailang Zhang............)
Date...........01 . 12 . 2023............

sign.................Xi kui Guo........... researcher
(Mr.Xikui Guo)
Date..............01 . 12 . 2023..........

ECMSU01-07.10 English 2023

Informed consent form for research from volunteers
(For volunteers over 18 years old)

I (Mr.) ......Yan bo...................... Surname ..Dong.................... Age 2002 Year.
House number ..9-5/14 Village No. ....\.... Sub-district Zhang ba gou District ....Yan ta...........
province..Shaan Xi...........
Convenient phone ......193 9093 0924.... ....

Read the explanation / listen to the explanation from Mr. Xikui Guo about volunteering in the research project on "Biomechanical Characteristics Analysis of Highly Difficult Movements '324C+1D' in Competitive Wushu Routine", the explanatory text consists of Full details about the purpose of the research, details of the research. That I have to do and be treated, the benefits that I may gain from the research and the risks that may arise from participating in the study. Including guidelines for questions that may arise throughout. It has also received an explanation and an answer to any questions from the research project leader.

As well as the testimony from the researcher that will keep my information confidential. In addition, not anonymously or private information individually to the public. The results of the research will be presented in the form of an overview that is a summary of the research results for academic purposes only.

"In participating as a volunteer of this research project I join voluntarily." And I can withdraw from this study at any time. If I wish which will not have any effect and will not lose any rights in study or work that I will receive in the future.

sign.........Yan bo Dong.............. Volunteers
(.......Mr. Yan bo Dong.........................)
Date..............01 . 12 . 2023..............

sign............Hai long Zhang... witness
(..........Mr.Hailang Zhang............)
Date.............01 . 12 . 2023............

sign.................Xi kui Guo......... researcher
(Mr.Xikui Guo)
Date.................01 . 12 . 2023............

ECMSU01-07.10 English 2023

Informed consent form for research from volunteers
(For volunteers over 18 years old)

I (Mr.) ......Liang........................ Surname ......Gao.................... Age.2001..Year.
House number ..9-511.. Village No. ....\..... Sub-district Zhang ba gou District ...Yan ta...........
province...Shaan Xi...........
Convenient phone ....19890930924..................

Read the explanation / listen to the explanation from Mr. Xikui Guo about volunteering in the research project on "Biomechanical Characteristics Analysis of Highly Difficult Movements '324C+1D' in Competitive Wushu Routine", the explanatory text consists of Full details about the purpose of the research, details of the research. That I have to do and be treated, the benefits that I may gain from the research and the risks that may arise from participating in the study. Including guidelines for questions that may arise throughout. It has also received an explanation and an answer to any questions from the research project leader.

As well as the testimony from the researcher that will keep my information confidential. In addition, not anonymously or private information individually to the public. The results of the research will be presented in the form of an overview that is a summary of the research results for academic purposes only.

"In participating as a volunteer of this research project I join voluntarily." And I can withdraw from this study at any time. If I wish which will not have any effect and will not lose any rights in study or work that I will receive in the future.

sign..........Liang Gao.................. Volunteers
(...............Mr. Liang Gao.......................)
Date..............01.12.2023.............

sign............Hailang Zhang.... witness
(..........Mr.Hailang Zhang............)
Date.............01.12.2023..............

sign.................Xikui Guo........... researcher
(Mr.Xikui Guo)
Date...........01.12.2023..............

Figure 34 Pre-test seminar

Figure 35 Testing instruments

Figure 36 The preparation of volunteers before the test

Figure 37 Action picture (1)

Figure 38 Action picture (2)

BIOGRAPHY

NAME	Mr.Xikui Guo
DATE OF BIRTH	April 11, 1982
PLACE OF BIRTH	Heze City, Shandong Province, China
ADDRESS	92 Yucai Road, Hanbin District, Ankang City, Shaanxi Province, China
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Research grants & awards	Shaanxi Provincial Sports Bureau Research Fund: Shaanxi Wushu Ecological Culture Construction research
Research output	Research paper 1 : Biomechanical analysis of 360° side somersault movement in Competitive wushu routine ; Research paper 2 : Research on the application of sports biomechanics in Competitive wushu routine