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Analyzing the Mechanism of Wushu Movements on Skill Enhancement and Injury Prevention through Mechanical Simulation Technology

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Abstract In this paper, we use 3D modeling software to establish a human body model by combining the data of martial arts movements. Through Newton's second law of motion force process “isolation method” research, calculate each link of the human body force situation. Using motion capture technology to compare and analyze the standardization of the athletes' wushu movements, and provide targeted guidance to prevent common patellar strain injuries. A controlled experiment was set up to compare the effects of wushu sports skill enhancement and injury prevention based on mechanics simulation technology and traditional teaching methods. The results showed that the average skill score of the experimental class assisted by mechanics simulation technology was 6.61 points higher than that of the control class, and the rate of individual goal achievement was 0.80-0.92. Only 8 people suffered from patellar strain injuries during the training process, and only 10 major injuries occurred during the season, and more than half of them did not need to undergo surgery. Wushu movement analysis through mechanical simulation can effectively improve athletes' skills and reduce the risk of injury.

Index Terms human body model, Newton's second law, wushu motion capture, patellar strain injury, mechanics simulation technology

I. Introduction

Wushu, as an important part of Chinese traditional culture, has a long history and deep cultural heritage [1]. However, with the rapid development of modern sports science, the traditional way of wushu training lacks scientific basis and theoretical support to a certain extent [2]. Sports biomechanics, as an interdisciplinary study of human movement and mechanics, can provide a new perspective for wushu training.

Sports biomechanics is a discipline involving biology, physics and medicine, which studies the mechanical characteristics of the human body in various movement states, explores the intrinsic laws of human movement, and provides theoretical support for the fields of sports training, physical education and rehabilitation medicine [3]. Sports biomechanics focuses on the mechanical factors of moment, angular velocity and impulse in human movement, as well as the effects of muscle, bone and joint biological structures on movement [4], [5]. Through the study of sports biomechanics, people can deeply understand the mystery of human movement, improve sports performance and prevent sports injuries, and then optimize the design of sports equipment [6], [7]. In traditional martial arts training, sports biomechanics also has an irreplaceable position. It can not only help coaches and athletes to master the technical essentials and improve the training effect, but also provide the basis for innovative wushu sports [8]-[10]. In addition, by studying the knowledge of sports biomechanics, coaches can guide training more scientifically, improve athletes' competitive performance, and contribute to athletes' physical health and reduce sports injuries [11]-[13]. In this context, the introduction of mechanics simulation technology to investigate the biomechanical changes in wushu training is of guiding significance in revealing the intrinsic mechanisms of wushu movements and optimizing training programs.

Modeling and calculating training forces on athletes plays a key role in improving athletic performance and reducing injury risk. This paper collects athletes' wushu movement data and uses modeling software to realize the manual modeling of the virtual human body. Combined with Newton's second law, the force process of wushu movements is calculated and analyzed to optimize the athletes' movement specification and reduce the injuries caused by wrong movements. Comparison of this paper's method with the traditional martial arts teaching methods of skill improvement level, injury, etc., to verify the effectiveness of the analysis of wushu movements based on mechanical simulation technology.

II. Optimization Path Analysis of Wushu Movements Based on Mechanical Simulation Technology

This chapter describes the process of utilizing mechanical simulation for martial arts movement skill enhancement and injury prevention, and analyzes how the relevant techniques work.

II. A.Establishment of human body model based on martial arts movement data

II. A. 1) Human body modeling

Martial arts action data should be bound with human characters to show, we can build different character models according to different needs. At present, the common human body modeling is divided into two ways: geometric manual modeling and photo automatic modeling. In this study, we mainly use 3DMAX software to model the virtual human body manually, starting from the regular geometry and gradually correcting the geometric surfaces to make the model gradually close to the human body model. While we emphasize the body structure modeling, we also put more emphasis on the recognition and processing of the human face, because we emphasize the importance of the action data, but also want to better preserve and show the original appearance of the action data presenter, especially for the protection of intangible cultural heritage, so we believe that the modeling of the human face model is also an extremely important part of the process. In face modeling, we use Face Gen Modeller software, through the character's front and left and right side three photos can be automatically modeled, and then output to 3DMAX software, model assembly, mapping and merging to get the final human body model.

II. A. 2) Human Model Binding Motion Data

After modeling the virtual human body in 3DMAX software, you need to bind the virtual human body to the martial arts action in Unity software. Binding requires three steps: set the animation for human animation such as, virtual human body skeleton configuration and martial arts action skeleton consistent, virtual human body binding animation. In Unity software, it is possible to create a variety of animations such as animal animation, human animation, etc. Human animation should be used for martial arts movements. The bone structure of different virtual human bodies can be different, and the bones can be flexibly configured in Unity software to make the virtual human body consistent with the bones in the martial arts motion capture data. Finally, the martial arts animation is bound in the animation controller of the virtual human body.

II. B.Newton's second law in martial arts sports

To cause a change in the state of motion of an object, a force must be applied to the object. Newton's second law reveals the relationship between the motion of an object and the force acting on it: when an object is subjected to a non-zero combined external force, the acceleration of the object's motion is proportional to the combined external force and inversely proportional to its mass. The direction of acceleration and the direction of the combined external force - consistent. It can be expressed by the formula:

$$\sum \vec{F} = ma \tag{1}$$

where $\sum \vec{F}$ denotes the vector of combined external forces acting on the object, m denotes the mass of the object, and a denotes the acceleration vector of the object's center-of-mass motion.

Wushu competition rules, in order to equalize the competitive ability, the difference between the participating athletes is not significant, the athletes will be divided into different levels according to their weight (mass). This is because the size of human inertia is related to mass. Athletes with large mass are inflexible, but have large inertia, good stability, and strong resistance to blows; athletes with small mass are flexible, but have poor stability and poor resistance to blows. Moreover, according to Newton's second law, when the combined external force is certain, the larger the mass of the athlete produces a smaller acceleration, the slower to change its state of motion, i.e., slow to dodge, slow to move, and slow to change their moves; whereas, the small mass of the athlete produces a large acceleration, the speed of the movement and the state of motion changes quickly, and in the confrontation, it is shown as a fast move and flexible changes.

The application of Newton's second law to the quantitative study of the human body is only applicable to the study of the motion of the mass point. When applying Newton's second law to deal with the dynamics of a multi-linked body in martial arts, the “isolation method” should be used. In the case of the human body, the so-called “isolation method” is to divide the multi-linked body into multiple links that can be regarded as mass points, so that each link can be regarded as a mass point and Newton's second law can be used directly. In this case, Newton's second law can be deformed as:

$$F = \sum_{i=1}^{n} m_i a_i \tag{2}$$

The following is the “isolation method” to analyze the force mechanism of the athlete's aerial flying foot jump. Let the total mass of the human body is M, the mass of each link is $m_1, m_2, m_3, \ldots m_n$, the corresponding acceleration is $a_1, a_2, a_3, \cdots a_n$. Assuming that the vertical ground direction is the y direction, and the horizontal direction parallel to the ground pointing to the direction of the athlete's rise is the x direction, a coordinate system is established. At this point, the force on the athlete is the force of gravity W and the reaction force provided by the ground F, and the equation is written according to Newton's second law as:

$$F + W = \sum_{i=1}^{n} m_i a_i \tag{3}$$

The component in the y direction is:

$$F_y + Mg = \sum_{i=1}^{n} m_i a_{iy} \tag{4}$$

Then the ground supports the body:

$$F_y = \sum_{i=1}^{n} m_i a_{iy} + Mg \tag{5}$$

Expand to get $F_y = m_1 a_{1y} + m_2 a_{2y} + m_3 a_{3y} + \cdots\cdots + m_n a_{ny} + Mg$

If the human body is broken down into four segments: foot, calf, thigh and the rest of the body, and the forces are analyzed, then the combined force supplied to the foot by the ground and calf is:

$$Fy - F_{12y} = m_1 g + m_1 a_{1y} \tag{6}$$

The combined force supplied to the calf by the foot and thigh is

$$F_{12y} - F_{23y} = m_2 g + m_2 a_{2y} \tag{7}$$

The combined force supplied to the thigh by the calf and the rest of the body is

$$F_{23y} - F_{34y} = m_3 g + m_3 a_{3y} \tag{8}$$

The force supplied by the thighs to the rest of the body is

$$F_{34y} = m_4\, g + m_4\, a_{4y} \tag{9}$$

Clearly, adding (6), (7), (8), and (9) gives Eq.

$$F_y = \sum_{i=1}^{n} m_i a_{iy} \tag{10}$$

Similarly, the force on the body in the horizontal direction (ground friction) is:

$$F_x = \sum_{i=1}^{n} m_i a_{ix} \tag{11}$$

From the above analysis, it can be seen that the calculation of the ground force F_x and F_y received by the athlete during the stepping and jumping process can be realized by simply giving the mass and center-of-mass acceleration of each part of the body.

The ΣF in Newton's second law can be either a constant force or a variable force. The forces in human motion are mainly variable, and we can use instantaneous forces and instantaneous accelerations in our research problems. The acceleration at each instant depends only on the action of the combined external force at the same instant.

Once the combined force is present, the acceleration occurs at the same time, and when the combined force is removed, the acceleration disappears.

Newton's second law studies the relationship between the combined external force on the body and the resulting acceleration. Whether the human body from static to dynamic, from dynamic to static or the size and direction of the speed change, are subject to the role of external forces, resulting in acceleration, that is to say, to utilize Newton's second law. The use of Newton's second law allows for a better analysis of the motion of the various parts of the human body by counting the motion of the various segments of the human body.

II. C.Optimization action analysis and evaluation

Through high-precision 3D capture and reconstruction of wushu movements, teachers are able to obtain all-round and multi-angle data of students' movements in wushu teaching. This data-based analysis allows teachers to accurately analyze and evaluate every detail of their students' movements, thus helping them to identify and correct erroneous movements and further improve the accuracy and standardization of their movements. In traditional Wushu teaching, instructors often rely on visual observation and empirical judgment to evaluate students' movement performance, which is not only highly subjective but also difficult to capture some subtle movement differences. The application of motion capture technology provides teachers with a more objective and scientific evaluation tool. By comparing and analyzing students' movement data with standard movement data, teachers can accurately point out students' deficiencies in movement execution and provide targeted suggestions for improvement. This precise way of analysis and evaluation not only helps to improve students' movement performance level, but also promotes the overall improvement of teaching quality. Teachers can formulate more personalized and scientific teaching plans based on students' movement data, thus better meeting students' learning needs. At the same time, by collecting and organizing a large amount of movement data, teachers can also conduct more in-depth teaching research, explore more effective teaching methods and means, and promote the continuous innovation and development of Wushu teaching.

II. D.Analysis of patellar strain in martial arts sports

Patellar strain is the most likely injury in wushu sports. There are more steps, jumps and leg movements in Wushu routines, which are the focus and difficulty in teaching and training, and at the same time, the loss of points in this part of the competition is also higher. Therefore, no matter in the wushu basic skills training or in the routine training, the greatest attention is given. For example, with the bow, horse, servant, virtual, resting step based on each step type body are in a semi-squatting position, the movement of the quadriceps muscle taut the tightest so that the patella and the femur between the contact surface is constantly increasing so as to increase the extrusion and friction. According to statistics, some athletes practice more than one hundred times a class or even more midway and no upper and lower limb movement alternately, so that the knee joint in continuous fatigue under repeated semi-squatting to change the step type, resulting in the knee joint localized load is too heavy, at this time the patella lurks in the factors of the injury. Not only that, but also in the set movement, wushu set movement between static and dynamic, fast and slow change frequently, step conversion is very much, the knee from the semi-squatting position or twisting, the patellar tendon collateral area to bear the tension is greater, patellofemoral articular surface produces a wrong movement, twisting, impact and friction. If these forces exceed the physiological load of the tissue cells, it will affect the local metabolism, leading to degeneration and necrosis of tissue cells, thus causing a series of pathological changes such as tendon fiber hemorrhage, degeneration, hyperplasia, calcification, and chondrocyte swelling, fibrosis, stripping. Therefore, long-term training can lead to patellar strain due to excessive load or accumulation of minor injuries. With the development of wushu sports to the direction of “difficult, beautiful, high, new”, increased some designated movements and innovative and difficult movements, such as; spinning body 360 or 720 ° spinning flying foot, external pendulum lotus, and so on, which also increases the knee joint of the unreasonable groove extrusion and twisting error. Long-term load exceeds the physiological limits of cartilage, preventing normal metabolism, the formation of chondroitin sulfate is affected, and the articular cartilage changes, leading to the occurrence of chondromalacia of the patella. Wushu sets in the jumping action, the designated action occupies a very important position. In the completion of jumping action, it is required to combine the footwork with bending the knee to jump, instant force, the impact on the knee joint is very large, at this time, the kneecap is most likely to be injured. When the human body is in the air, different groups of jumping action in the air must also complete the corresponding rotation and leg method, then the knee joint must be the second force, such as the whirlwind leg, etc., which makes the inner and outer collateral ligaments of the knee joint and meniscus easy to be injured. After the completion of the vacated, the landing of the connecting action is also very rich, such as the whirlwind leg to the horse stance, whirlwind leg to the splits, external pendulum lotus, etc., these actions require good stability, and in the instantaneous completion of almost no buffer, and some even single-footed landing, so

that the human body gravity, the rapid release of rotational force, increasing the crotch joints, the knee joints, ankle joints, especially in the completion of the specified action, due to the specified action design are difficult to complete. Especially in the completion of the designated movements, because the design of the designated movements have a certain degree of difficulty, and some even conflict with the human body's rules and habits of movement, which makes the crotch joints, knee joints, ankle joints greatly increase the possibility of injury.

III. Controlled experiments and analysis of results

In order to judge the specific effect of analyzing wushu movements based on the mechanics simulation technique proposed in this paper, this chapter sets up a controlled experiment for verification. Two classes of students from a university's martial arts academy were selected as the experimental subjects. 30 students were enrolled in both classes, and the initial level of the students' martial arts movements was comparable. Wushu class 1 was used as the experimental class (experimental teaching using mechanics simulation technology) and Wushu class 2 as the control class (teaching using traditional teaching methods), with no other variables except the teaching methods. The experiment lasted for one academic year, and the students' final skill levels and injuries during the academic year were used as research data to compare and analyze the actual usefulness of the 2 methods

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III. A. Comparison of Martial Arts Movement Skill Improvement

III. A. 1) Comparison of Martial Arts Movement Skills Performance

According to the course objective 1 and season requirement 2, students need to have a good level of physical fitness, solid wushu movement techniques, practice methods and tools after the wushu course to meet the assessment standards of wushu movement skills in collegiate wushu academies. Figure 1 shows the statistics of the final grades of wushu movement skills of the students in the experimental class and the control class. Table 1 shows the T-test results of the final grades of wushu movement skills of the students in the experimental class and the control class. As can be seen from Figure 1, the average score of the final skills achievement in wushu movements of the students in the experimental class is 86.95, and the average score of the final skills achievement in wushu movements of the students in the control class is 80.34, and it is found that the average score of the final skills achievement in wushu movements of the experimental class is higher than that of the average score of the final skills achievement in wushu movements of the control class by 6.61 points. The analysis of the final martial arts movement scores concluded that the use of mechanical simulation technology analysis method for the martial arts class can improve the students' martial arts movement skill scores. Continuing to analyze Table 1, it was found that: at t=0.03, P=0.04<a=0.05, a small probability event occurs, indicating that the difference between the experimental class students' wushu movement final skill achievement and the control class students' wushu movement final skill achievement is obvious, indicating that the teaching mode based on the analysis method of mechanical simulation technology and the traditional teaching mode of wushu has a significant difference on the achievement of the wushu movement set. The use of mechanics simulation technology analysis method for auxiliary teaching in wushu class can improve students' wushu movement skill level.

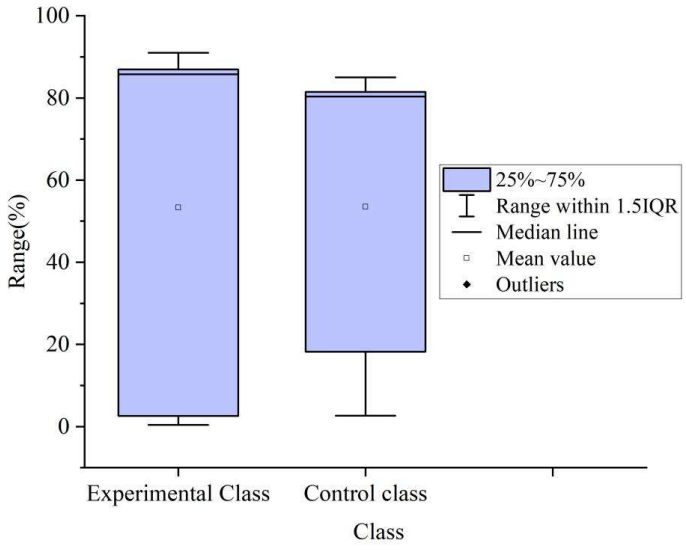

Figure 1: Comparison of final grades of martial arts movement skills(N=30)

Table 1: T-test results of the final grades of martial arts movement skills(N=30)

		Achievements in martial arts movement skills	
		Assume equal variance	Not assume equal variance
F		4.947	-
Sig.		0.027	-
T		0.03	0.03
D		30	30
Sig. (double tail)		0.04	0.04
Average value difference		6.610	6.610
Standard error difference		2.514	2.514
95% confidence interval	Lower limit	-3.325	-3.416
	Upper limit	7.309	7.367

III. A. 2) Comparison of individual goal attainment

Figure 2 shows a comparison of the achievement of personal goals in martial arts movement between the students in the experimental class and the control class. In terms of students' personal goal attainment, the experimental class students' final grade attainment rate of wushu movement skills was concentrated between 0.80 and 0.92, while the control class students' final grade attainment rate was concentrated between 0.55 and 0.80. The results showed that the personal goal achievement rate of the students in the experimental class was much higher than that of the students in the control class. And from the point of view of the overall achievement of the class, the personal goal achievement rate of the students in the control class fluctuates greatly, indicating that the overall level within the control class is not as good as the average of the students in the experimental class. It shows that: under the teaching aided by mechanics simulation technology, it can better help the experimental class students learn and correct the deficiencies of wushu movements and achieve the ideal personal goals; while the traditional teaching method is not obvious in the effect of improving the skills of wushu movements due to relying on the teacher's subjective observation only.

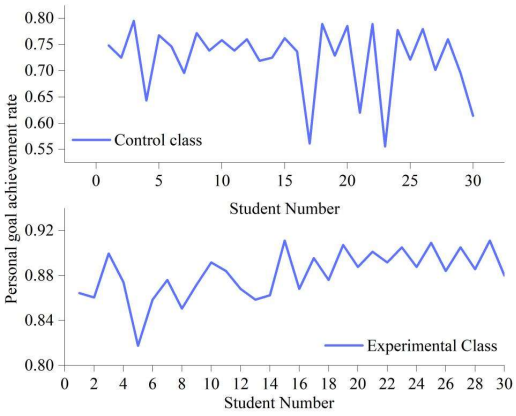

Figure 2: Comparison of personal goal achievement

III. B. Analysis of Martial Arts Movement Injuries

III. B. 1) Survey statistics on types of sports injuries in experimental classes

Each student develops one or more injuries during training. Further investigation yielded the major types of injuries that occurred in the experimental class of students during the one academic year of the controlled experiment. Figure 3 shows the statistical results of the investigation. During the training process of one academic year, 20 students in the experimental class had muscle strains, accounting for 35.71% of the injury ratio; 8 students had patellar strain, accounting for 14.29%; and 28 students had ligament injuries, accounting for 50%. It can be seen that the number of students with patellar strain is only 8 people, accounting for a relatively low percentage, indicating that the use of mechanics simulation technology for assisted teaching can prevent students from overworking the patella in the case of injury.

III. B. 2) Statistics on the investigation of sports injury sites in the control class

Table 2 shows the results of the investigation of the sports injury sites of the students in the control class. The data statistics in Table 2 show that the injury sites of students in the control class were mostly concentrated in the patella,

femur, knee, hip, and ankle joints, which amounted to 25, 23, 28, 19, and 16 times, respectively, with a total percentage of 86.05%. Because of the subjective observation of students' wushu sports performance by coaches only, it is impossible to get the accurate force situation, which leads to a large number of patella-related parts strain and joint degradation of students in long-time, high-intensity wushu training. The overall comparison shows that the injury prevention effect of traditional wushu teaching methods is not as effective as the effect of utilizing mechanics simulation technology for assisted teaching.

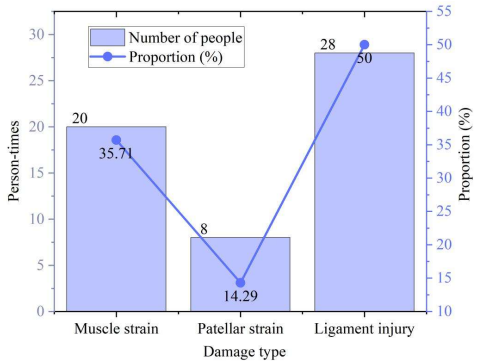

Figure 3: The types of sports injuries in the experimental class

Table 2: The sports injury sites of the students in the control class

Damaged part	Person-times	Proportion (%)
Patella	25	19.38
Femur	23	17.83
Knee joint	28	21.71
Hip joint	19	14.73
Ankle joint	16	12.40
Wrist	10	7.75
Shoulder	8	6.20
Total	129	100

III. C. Comparison of the number of major injuries in martial arts competitions

III. C. 1) Statistics of major sports injuries in the experimental classes

The significant injury (more than 7 days of post-injury suspension) situation during the martial arts season provides good evidence of the effectiveness of the 2 methods for preventing injuries in martial arts maneuvers. Therefore, in this section, the data of major injuries during the season of students in both classes were counted and the results were analyzed. Table 3 shows the statistical results of major sports injuries during the season in the experimental class. During the season, there were 10 major injuries among the students in the experimental class, and there were no injuries with patellar strain, and the number of those requiring surgery was four. The number of major injuries in the intense tournament was small, and due to the prediction of these possible major injuries through mechanical simulation technology in advance, emergency measures were taken to treat them in time, and the number of students who needed surgery in the end was not more than half of the number of injuries.

Table 3: Statistics of major sports injuries during the experimental class season

Damage type	Person-times	Number of surgeries
Thigh muscle strain	5	0
Tear of the meniscus of the knee	1	0
Tear of the medial collateral ligament of the knee	1	1
Patellar strain	0	0
Achilles tendon rupture	1	1
Dislocation of the carpal moon bone	0	0
Fracture of the scaphoid bone of the wrist	1	1
Clavicle fracture	1	1
Total	10	4

III. C. 2) Statistics of major sports injuries in control classes

Table 4 shows the statistics of major sports injuries during the control class season. There were 21 major injuries, 4 patellar strains and 12 surgeries in the control class. Comparing the major injuries in the experimental class and the control class, it can be seen that the number of major injuries and the number of surgeries performed in the control class is much higher than that in the experimental class. This shows that traditional teaching methods cannot properly help teachers to understand the students' physical condition during the practice of martial arts movements, which makes it difficult to prevent injuries. The comparison results also proved once again the value of the application of mechanical simulation technology in the prevention and treatment of wushu movement injuries.

Table 4: Statistics of major sports injuries during the Control class

Damage type	Person-times	Number of surgeries
Thigh muscle strain	8	2
Tear of the meniscus of the knee	2	2
Tear of the medial collateral ligament of the knee	1	1
Patellar strain	4	1
Achilles tendon rupture	2	2
Dislocation of the carpal moon bone	1	1
Fracture of the scaphoid bone of the wrist	2	2
Clavicle fracture	1	1
Total	21	12

IV. Conclusion

This paper models and calculates forces on athletes' wushu movement data to achieve movement-targeted correction and injury prevention. In the control experiment, the average score of students' wushu movement skills in the experimental class was 86.95, which was higher than the 80.34 of the control class. The personal goal achievement rate was stable between 0.80 and 0.92, again higher than the control class. There were 14.29% of visits with patellar strain, and 10 major injuries during the season, most of which did not require surgery. The application of mechanical simulation technology in teaching martial arts movement analysis can improve students' martial arts movement skill level and reduce injuries. In the future, it can be further combined with depth sensors and other hardware to collect real-time force data during students' movement and improve the real-time movement correction.

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