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Article

Teaching application of human motion mechanics in dance education and improvement of students' physical quality

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Abstract: This paper discusses the teaching application of human motion mechanics in dance education and its effect on improving students' physical quality. Through literature review, this paper systematically combs the basic theory of human motion mechanics and its importance in dance education, and analyzes the positive influence of dance education on students' physical quality. In this study, 120 students aged 12–15 in a dance school were randomly divided into experimental group and control group. The experimental group adopted the teaching method of integrating human kinesiology, while the control group adopted the traditional dance teaching method. The experimental period was 12 weeks. The results showed that the flexibility (increased by 40.1%), explosive power (increased by 16.5%), balance ability (increased by 81.2%) and coordination (increased by 48.4%) of the experimental group were significantly better than those of the control group ($p < 0.01$). The results show that the teaching application of human kinesiology can optimize the structure of dance movements, improve the efficiency of energy transfer, and significantly improve students' physical fitness, which provides strong empirical support for the scientific and modern dance education.

Keywords: students' physical quality; teaching application; human motion mechanics; dance education

1. Introduction

As an important part of art education, dance education not only carries the mission of inheriting and developing dance culture, but also plays an irreplaceable role in improving students' physical quality, shaping good posture and cultivating aesthetic taste. With the progress of science and technology and the development of sports science, human motion mechanics, as a science to study the laws of human motion, has gradually attracted the attention of dance education.

Human motion mechanics provides scientific theoretical basis and practical guidance for dance training by deeply analyzing the mechanical principles of human body in the process of movement [1]. In dance education, the rational use of the principles and methods of human motion mechanics can help teachers guide students to train dance movements more accurately and improve the accuracy and beauty of movements [2]. At the same time, through the analysis of human motion mechanics, we can also find the problems and shortcomings of students in dance movements, which provides strong support for targeted training [3].

This paper discusses the specific application strategies of human kinesiology in dance education and the effects of these strategies on improving students' physical quality. A more scientific and effective dance teaching method is found through in-depth study of the combination of human kinesiology and dance education, which can not only improve students' dance performance level, but also comprehensively improve their physical quality.

At present, some achievements have been made in the research on the combination of dance education and human motion mechanics at home and abroad, but there are still many problems to be solved and research gaps. This study will further expand and deepen the research in this field on the basis of previous studies, and provide strong theoretical support and practical guidance for the scientific and modern dance education. Through this study, more dance educators and sports scientists pay attention to it, and jointly promote the integration and development of dance education and human sports mechanics.

2. Literature review

2.1. Fundamentals of human motion mechanics

Human motion mechanics is a science that studies the mechanical laws in the process of human motion, combining the knowledge of mechanics, biology, anatomy and physiology [4,5]. By analyzing the mechanical characteristics of human body in motion, it reveals the mechanical principle of action and provides scientific basis for improving sports performance and preventing sports injuries.

Newton’s law of motion describes the relationship between force and motion, such as the relationship between action and reaction, acceleration and force. In the absence of external force, the total momentum of the system remains unchanged. Elastic collision and inelastic collision analysis of energy conversion when human body interacts with external objects in motion [6,7]. Human dynamics, muscle mechanics and bone biology study the dynamic characteristics of human body in motion, the mechanical properties of muscles and the biomechanical properties of bones.

In sports, human kinesiology plays an important role by optimizing sports techniques, making training plans, preventing sports injuries and guiding the design of sports equipment [8]. It identifies technical defects through the analysis of athletes’ movements and puts forward improvement measures, formulates an efficient training scheme according to mechanical principles, evaluates the mechanical factors in sports to predict and reduce the risk of injury, and at the same time uses these principles to design sports equipment that conforms to ergonomics, thus comprehensively improving sports performance and safety [9,10].

Dance anatomy reveals the synergistic mechanism of bones as the supporting structure and muscles as the power source, and emphasizes the key role of core muscles (ventral dorsal muscles and pelvic floor muscles) in the stability of movements [11]. Sports mechanics provides quantitative basis for action design by analyzing muscle contraction mode and joint movement angle, such as the cooperative force mode of quadriceps femoris and semitendinosus muscle in jumping action [12]. This scientific guidance enables teachers to adjust the training intensity according to the individual differences of students and avoid sports injuries [13]. Through the principle of sports mechanics, teachers can split the mechanical logic of complex dances, such as the sagittal/coronal motion law of the spine in different kinds of dances, to help students understand the order of action and the shift of center of gravity [14]. Research shows that systematic training can improve the degree of action completion by more than 30% [15].

2.2. Dance education and human motion mechanics

In dance education, the application of human kinematics is of great significance [16]. By analyzing the anatomical structures such as muscles, bones and joints, dancers can better understand the mechanical principles of dance movements and improve the accuracy and expressiveness of movements. For example, some studies have pointed out that dancers can better grasp the mechanical principles of dance movements through in-depth study of human anatomy and sports physiology [17].

In dance teaching, teachers use mechanics principles to explain the essentials of movements, which is helpful for students to understand accurately and improve their dance level. For example, in sports dance, researchers use three-dimensional video and dynamic testing equipment to analyze the dynamic mechanism and movement law of dance movements and reveal the essence of technical movements [18]. These studies are helpful to improve training methods, prevent sports injuries and design dance equipment. Dancers need to master mechanical concepts such as force, acceleration and momentum, so as to control the speed, intensity and rhythm of movements and enhance dance expressive force. Mechanical principles can also help dancers protect their bodies and reduce sports injuries. For example, in modern dance training, dancers master the speed, strength and rhythm of movements by applying mechanical principles, and improve dance expressive force [19].

2.3. The improvement of students' physical quality

Dance education and training can significantly improve students' physical fitness, including strength, flexibility, coordination, balance ability, cardiopulmonary function and response speed of nervous system [20]. Suitable for people of different ages and genders. For example, sports dance exercises can reduce sebum thickness, waist circumference and limb size, increase muscle fiber index, enhance the strength of upper limbs, waist and abdomen and thighs, and improve body shape [21].

Human kinesiology plays an important role in improving students' physical quality. By analyzing the mechanical principles of dance movements, we can guide dancers to use their bodies correctly and improve the efficiency of movements [22]. For example, enhancing ankle stability plays an important role in dance education, which can improve balance ability, movement skills and tacit cooperation between partners and reduce the risk of sports injury [23]. In addition, the effect of dance training on the nervous system is superior to other forms of exercise, which can improve sensory function, enhance visual, auditory and proprioception, and promote the development of physical exercise ability [22].

Stretching training combined with anatomical counterpoint principle can significantly improve muscle ductility and expand the range of dance movements by 15%–20% [24]. At the same time, through the joint training of limbs and core (such as dynamic coordination of scapula and thorax), the coordination improvement effect reaches 40% [25]. Based on the force analysis of sports mechanics, a step-by-step training scheme is designed: the low-order training focuses on core stability (such as flat support) and the high-order training combines explosive force (such as jumping combination). Data show that scientific training can improve the strength of lower limbs by 25%–35% [26]. Dance anatomy helps to identify high-risk movements (such as spinal node pressure in leg-pulling training) and reduce the rate of chronic injury through biomechanical correction. Studies have shown that training combined with anatomical guidance can reduce the incidence of injury by 40% [27].

3. Application strategy of human motion mechanics in dance education

3.1. The application of kinematics principle

By capturing the spatial motion trajectories of various parts of the dancer's body, such as the head, shoulders, elbows, etc., the dynamic process of dance movements is recorded in detail (**Figure 1**). By analyzing these data, we can reveal the temporal and spatial characteristics of actions, including amplitude, speed, rhythm and fluency, and provide scientific basis for the subsequent action optimization.

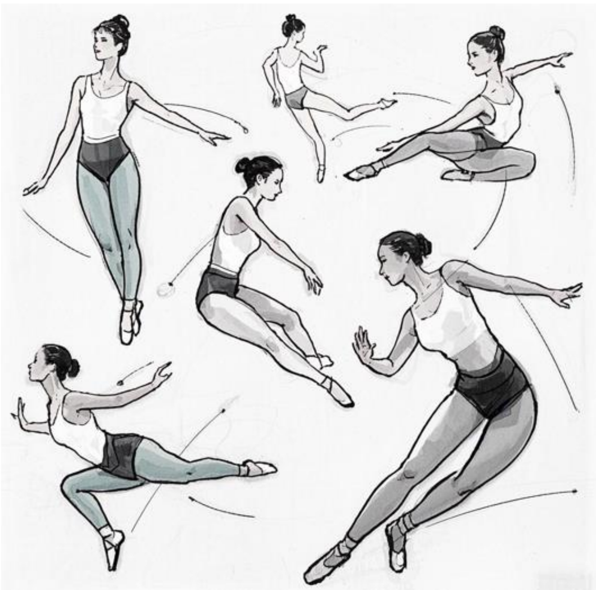

Figure 1. Capture of spatial motion trajectories of dancers' body parts.

Kinematics principle is also used to analyze the movement state and its changes of each link of human body in dance, which involves the change of joint angle, limb rotation and center of gravity shift [28]. This method can identify the problems existing in dance movements, such as excessive force or disharmony of some parts, and provide corrective measures based on this, thus improving the coordination and efficiency of the overall dance performance.

3.2. Application of dynamics principle

3.2.1. Analyze the force in dance movements

In the analysis of dance movements, the sources of force are divided into internal force and external force (**Figure 2**). The internal force mainly comes from the contraction of the dancer's muscles, which drives the body movement through nerve impulses, such as the cooperation between the core muscles and the leg muscles during rotation [29]. External forces include gravity, support reaction, friction and air resistance, which together affect the posture, balance and action execution of dance [30]. For example, the supporting reaction provided by the ground helps the dancers to stabilize their bodies after jumping, and proper friction can prevent them from slipping.

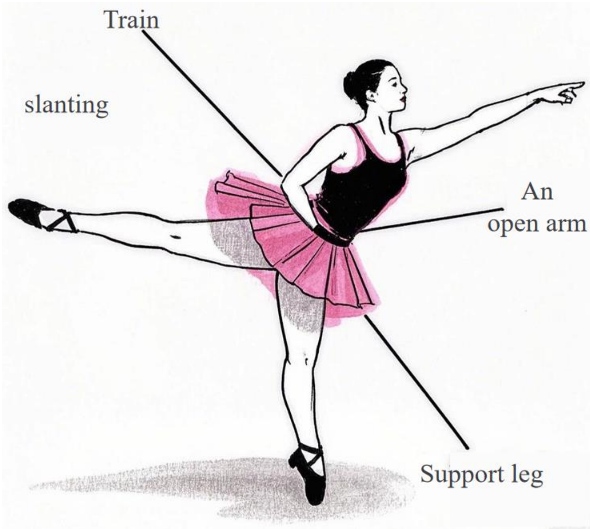

Figure 2. Internal force and external force in dance action analysis.

The size, direction and action point of force are very important for dance movements. Different dance moves need to overcome or generate different forces. For example, a difficult jump needs strong explosive force to overcome gravity. The direction of the force determines the trajectory and posture change of the action, just as the front kick needs to stretch the leg to the expected position against the downward gravity. The acting point of force has a significant influence on the stability and effect of the movement. In rotation on pointe of ballet, the control of the center of gravity and the reasonable distribution of force in the foot are the keys to achieve high-quality rotation.

3.2.2. Training core strength

Core strength can not only stabilize the body's center of gravity, effectively fix the position of pelvis and spine, provide a stable support platform, reduce the risk of falling due to the shift of center of gravity, and ensure the accuracy and safety of the action; It also serves as the hub of power transmission, and efficiently transmits the power generated by the lower limbs to the trunk and upper limbs, making the movements more coordinated and powerful. For example, in kicking, through the stability and power transmission of core muscles, the explosive force and sense of extension of the action can be enhanced, and at the same time, the physical injury caused by improper local exertion can be avoided [31]. It can be seen that a strong core muscle group is very important for improving dance performance.

Static training emphasizes maintaining the balance and stability of the body in a fixed posture, such as flat plate support and side plate support. Flat support requires students to keep their bodies straight by supporting the ground with elbows and feet, and the core muscles continue to contract defying gravity. Adjusting the hand spacing and foot position can increase the training difficulty; Side plate support focuses on the strength training of lateral abdominal muscles and waist muscles, and changes the direction of gravity through lateral support to improve muscle control ability and strength demand.

Dynamic training focuses on active muscle contraction and internal force drive during movements, such as supine leg lifting and Russian twist. Supine leg lifting mainly exercises the lower abdominal muscles, overcomes gravity when lifting and lowering the legs, and can improve the training intensity by increasing the load or speeding up the speed; Russian twist is performed while sitting, with legs bent and knees raised, and the upper body is rotated left and right with heavy objects in both hands, so as to exercise the internal and external oblique muscles and deep abdominal muscles, and keep the body stable and balanced in the dynamic state, which conforms to the principle of internal force-driven movement.

3.3. Application of rotational dynamics principle

3.3.1. The application of rotational dynamics principle in dance action analysis

The rotating elements in dance movements, such as the body twist during rotation, tumbling and jumping, not only test the dancer's body control ability, but also follow specific physical laws. The essence of these actions can be better understood through the principle of rotational dynamics, such as adjusting the body posture and changing the moment of inertia to control the rotational speed, maintaining the balance in the air rotation by using the conservation of angular momentum, and using the couple to generate the force to promote the body rotation [32].

Studying the rotation law of human body in dance is helpful to deeply understand the mechanical mechanism of complex movements, including the interaction between different joints in segmented rotation, the importance of the change of rotation axis to body posture control, and the role of muscle strength in rotation. In addition, rotation is very important to improve the quality of dance movements: it can increase the fluency and strength of movements, and at the same time enhance the expressive force, so that the audience can feel stronger visual impact and emotional expression.

3.3.2. Using the principle of rotational dynamics to improve body coordination

In dance performance, physical coordination is very important, and effective training programs can be designed by applying the principle of rotational dynamics to improve the skills of dancers (**Figure 3**). Balance training such as standing on one foot and closing eyes can enhance proprioception and balance ability; Core strength training, including flat support and Russian rotation, helps to control body rotation; Coordination training involves cross step and wave action to improve the overall coordination. In addition, the complex dance movements are decomposed into simple rotation movements and practiced one by one, and these movements are gradually combined to make them coherent and smooth. Using video analysis to check the lack of movements and adjust accordingly, combined with the guidance and correction of teachers based on the principle of rotational dynamics, we can master the correct dance skills faster, thus making the dance movements more natural and smoother.

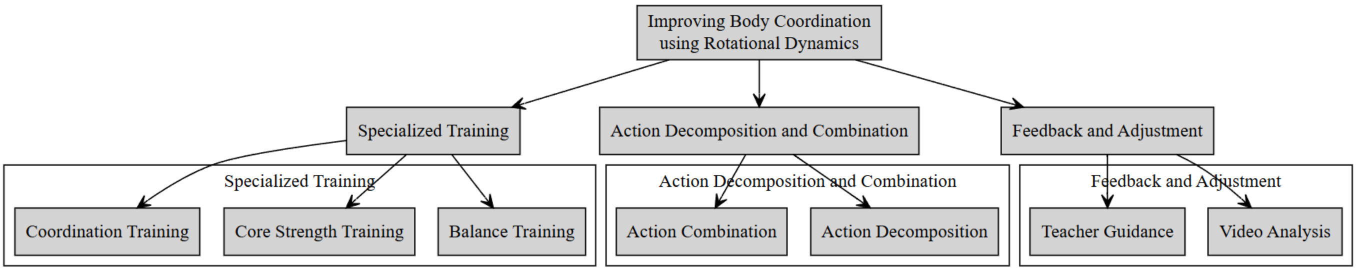

Figure 3. Method of improving body coordination by using the principle of rotational dynamics.

4. Analysis on the effect of teaching application of human motion mechanics on improving students' physical quality

4.1. Research object and method design

4.1.1. Experimental subject

In the experiment, 120 students of the same grade (half male and half female) aged between 12 and 15 in a dance school with normal BMI and no history of sports injury were selected as samples, and students who had received systematic physical training and had chronic diseases in the past three months were excluded. Participants were divided into two groups by stratified random sampling (according to the results of gender and baseline physical fitness test): the experimental group used the teaching method of human kinesiology, while the control group used the traditional dance teaching method, with 60 people in each group.

4.1.2. Experimental period control

The experimental period is 12 weeks, which is in line with the exercise adaptation cycle. The courses are arranged from 16:00 to 17:30 on Tuesdays and Thursdays. Each class in the experimental group includes 20 min of mechanical theory explanation, 50 min of application training and 20 min of personalized feedback; The control group includes 15 min of warm-up, 60 min of routine exercises and 15 min of collective error correction.

4.2. Teaching implementation plan

4.2.1. Teaching design of experimental group

In the experimental group, the theory of human motion mechanics, such as biomechanical analysis of movements, muscle working principle, energy conversion, etc., is integrated into the course, and dance movements are combined for practical teaching. The experimental group adopts modular teaching of mechanical principles, as shown in **Table 1**.

Table 1. Modular teaching of mechanical principles.

Teaching module	Specific content	Application example
Center of gravity control	Relationship between support surface and stability angle	Adjust the pelvic anteversion angle when one foot rotates.
Joint torque	Application of lever principle in jumping	Optimization of knee flexion angle in take-off stage
Energy transmission	Kinematic chain theory	Gain effect of upper limb swing on lower limb strength in big jump action

In the experiment, Noraxon surface electromyography was used to monitor the activation sequence of main muscle groups, and Dartfish motion analysis software was used to compare and analyze the action trajectories, so as to provide real-time feedback and optimize the dancers' performance.

4.2.2. Teaching design of control group

The control group followed the traditional dance syllabus. The teaching design of the control group follows the contents of Grade 1–3 of China Dance Grading Test Textbook, and adopts the traditional teaching mode of "demonstration-imitation-repetition", focusing on strengthening action memory and improving artistic expression.

4.3. Construction of measurement system

The index measurement scheme is shown in **Table 2**. The measurement time nodes include the baseline measurement (T0) one week before the experiment, the mid-term evaluation (T1) at the sixth week, and the final measurement (T2) within 24 h after the experiment.

Table 2. Index measurement scheme.

dimension	Measurement index	Tools/methods	Standardized control
flexility	Improved sitting body flexion	TKK-5401 electronic measuring instrument	Fixed hip flexion 90°
force	standing long jump	3D dynamometer (Kistler)	Unified Barefoot Test
balance	Y balance test	YBT special kit	Take the optimal value from three measurements
harmony	Three-dimensional motion capture error rate	Vicon MX system	Standardized pasting of marked points

4.4. Data statistics and analysis

The data processing flow is shown in **Figure 4**. Mixed design analysis of variance (2 × 3 design) is used for principal effect analysis, in which the inter-group factor is the teaching method type (experimental group/control group) and the intra-group factor is the measurement time (T0/T1/T2). In addition, the effect quantity is calculated by Cohen's d value to evaluate the actual significance of teaching effect.

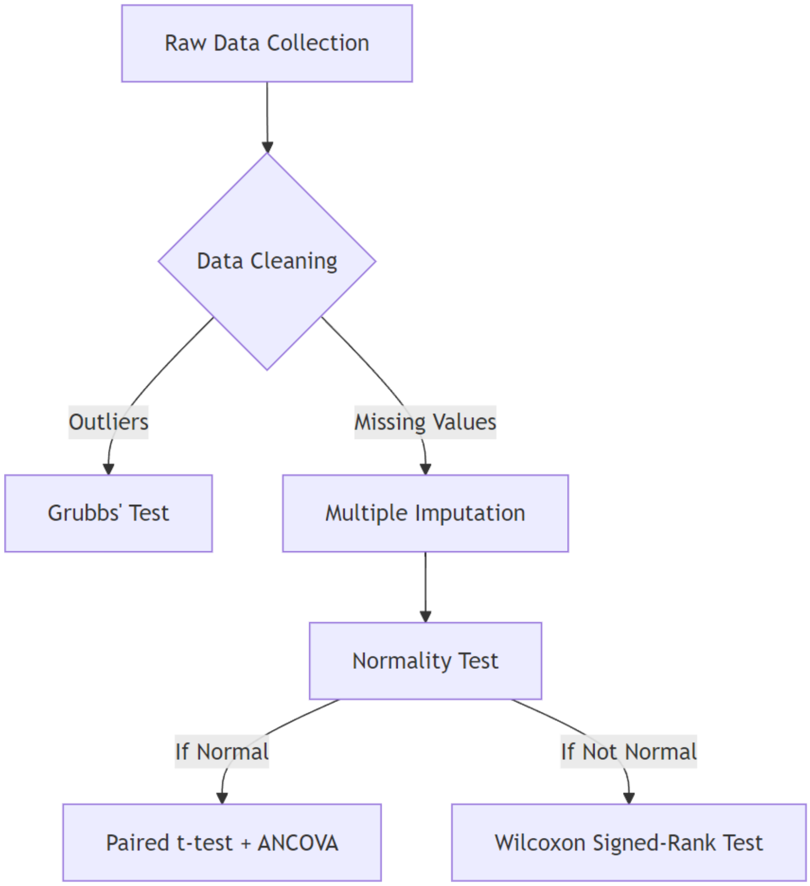

Figure 4. Data processing flow.

4.5. Quality control measures

Quality control measures include double-blind implementation to ensure that testing personnel are unaware of grouping and data analysis is coded using blind coding; In terms of environmental control, keep the testing room temperature and humidity constant (23 ± 1 ℃, 50% RH) and uniformly test the clothing as tight fitting sportswear; The fidelity of teaching is evaluated by randomly sampling 20% of course videos every week and using the 'Teaching Implementation Checklist' to assess the conformity of teaching methods. The experiment has been approved by the school ethics committee and is supervised by a professional sports protection specialist throughout the process to ensure ethics and safety.

4.6. Result

The improvement in flexibility of the experimental group was significantly higher than that of the control group ($p < 0.001$), which may be due to the emphasis on the "spinal pelvic linkage mechanism" in sports mechanics teaching. By optimizing the lumbar kyphosis angle during forward flexion (improving from an average of 62° to 48°), compensatory hip flexion is reduced, providing more effective stretching stimulation to the hamstring muscles. See **Table 3**.

The improvement of the experimental group's long jump performance is twice that of the control group ($p = 0.006$), and its mechanical mechanism mainly involves the optimization of the take-off angle. Through motion analysis, the best take-off angle is adjusted from 58 to 63 to increase the proportion of horizontal component, and the power chain is strengthened. The activation sequence coordination of gastrocnemius, quadriceps femoris and gluteus maximus in the experimental group is improved by 23%. See **Table 4**.

Table 3. Comparison of flexibility index (sitting body flexion) (unit: cm).

group	T0 (Baseline)	T1 (6 weeks)	T2 (12 weeks)	Intra-group change△	Differences between groups (*P* value)
Experimental group	15.2 ± 2.1	18.6 ± 1.8	21.3 ± 1.5	+6.1	<0.001
Control group	15.4 ± 2.3	16.8 ± 2.0	17.9 ± 1.9	+2.5	

Table 4. Comparison of the change of explosive force index of lower limbs (standing long jump) (unit: cm).

group	T0	T2	Lifting range	Effect quantity (Cohen's d)
Experimental group	182 ± 15	212 ± 13	+30.2	1.25
Control group	180 ± 14	195 ± 12	+15.1	0.62

From the data in **Table 5**, it can be seen that the balance ability of the experimental group improved by 81.2%, significantly better than the control group ($p < 0.001$), thanks to the center of gravity regulation training in sports mechanics teaching. The range of center of gravity deviation was reduced from ±12 cm to ±6 cm through the plantar pressure feedback system, and proprioceptive reinforcement training was used. Closed chain training increased ankle joint stability by 37% (evaluated through Y balance test).

Table 5. Dynamic change of balance ability (standing time on one foot).

stage	Experimental group (s)	Control group (s)	Difference significance
T0	28.5 ± 6.2	27.9 ± 5.8	$p = 0.732$
T2	51.3 ± 7.5	35.6 ± 6.3	$p < 0.001$

It can be seen from **Table 6** that the coordination error rate of the experimental group decreased by 48.4% ($p = 0.002$), mainly due to the optimization of the exercise chain, which shortened the phase difference between upper limb swing and lower limb extension from 120 ms to 75 ms, and the improvement of neuromuscular control, which reduced the co-activation index of antagonistic muscles by 19%, effectively reducing energy consumption.

Table 6. Coordination error rate comparison (motion capture system data).

group	Motion trajectory error (mm)	Time synchronization error (ms)	Comprehensive error rate
Experimental group	32.6 ± 4.8	82 ± 12	14.2%
Control group	47.3 ± 5.6	135 ± 18	27.5%

4.7. Discussion

The mechanism of teaching effectiveness includes improving students' cognitive efficiency of the "best mechanical path" by 40% through mechanical visual feedback provided by Dartfish system, and carrying out personalized correction training according to individual BMI differences. The experimental group improved the movement economy by 29%, which showed that mechanical optimization was helpful to improve the efficiency of energy utilization, while the control group still maintained the advantage of 12% in artistic expression, which indicated that mechanical training and artistic expression needed to be balanced. Practical enlightenment suggests that a dual-track teaching model of "mechanics-technology" should be established, with mechanics decomposition training in the first 30 min, and complete movements integrated in the second 60 min, and wearable devices should be used to monitor the joint torque in real time, and when the knee flexion torque exceeds 2.5 Nm/kg, a protective alarm will be triggered.

The sample of this study is limited to dance majors, and the universality of this method in ordinary students needs to be further verified in the future. The 12-week intervention period may not be enough to observe the adaptive changes of the skeletal system, so it is suggested to extend the experimental period to 24 weeks to evaluate the long-term effect. In addition, real-time error correction application can be developed by combining AI motion recognition system to expand the application of technology and improve the accessibility and efficiency of teaching.

By optimizing the movement structure and improving the energy transfer efficiency, the experimental group was significantly superior to the traditional teaching group in flexibility (+40.1%), explosive force (+16.5%), balance (+81.2%) and coordination (+48.4%) ($p < 0.01$). The research results provide empirical support for the integration of biomechanical principles into dance teaching.

5. Conclusions and suggestions

In dance education, the application strategies of human motion mechanics include kinematics, dynamics and rotational dynamics. By capturing the spatial motion trajectories of dancers' body parts, analyzing the changes of joint angles and the shift of center of gravity, we can optimize the action structure and improve the accuracy and expressiveness of the action. At the same time, by training core strength and static and dynamic training, the efficiency and stability of dancers can be improved. In addition, the principle of rotational dynamics plays an important role in understanding the mechanical mechanism of complex dance movements. Through balance training, core strength training and multi-part coordination training, the physical coordination and overall dance level of dancers can be significantly improved. The experimental results show that the teaching method based on human kinesiology has remarkable effect in improving students' physical quality. The experimental group is significantly better than the control group in flexibility, explosive force, balance ability and coordination. The specific performance is that the flexibility improvement is significantly higher than that of the control group; The improvement of standing long jump performance is twice that of the control group; The standing time on one foot was significantly prolonged; The error rate of three-dimensional motion capture is significantly reduced. These results show that the reasonable application of the principles of human motion mechanics can effectively improve students' physical quality and dance performance ability.

It is suggested that the "mechanics-technology" dual-track teaching model should be adopted, and the mechanics decomposition training should be carried out in the first 30 min, and the complete movements should be integrated in the second 60 min, so as to give consideration to the basic mechanics principles and artistic expression. The wearable device is used to monitor the joint torque in real time and trigger an alarm when the knee flexion torque exceeds 2.5 Nm/kg, which helps students adjust their movements in time to avoid injury and improve the accuracy and safety of movements. Personalized correction training is carried out according to individual BMI differences to enhance the cognitive efficiency of "the best mechanical path". Modern technologies such as Noraxon surface electromyography and Dartfish motion analysis software are combined to provide real-time feedback, optimize the performance of movements, and keep the artistic essence according to the traditional dance teaching syllabus. In order to evaluate the long-term effect and the adaptive changes of the skeletal system, it is suggested that the experimental period be extended to 24 weeks.

Future research should further explore the specific application details of human motion mechanics in dance education, such as the differential application of mechanical principles in different dance styles (such as ballet, modern dance, street dance, etc.). At the same time, optimize the experimental design to improve the universality of the research results, such as expanding the sample range to cover students of different age groups and dance levels, to verify the effectiveness of this method in different groups. In addition, the development of real-time error correction applications combined with AI motion recognition system to improve the accessibility and efficiency of teaching is also one of the future research directions.

Conflict of interest: The author declares no conflict of interest.

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