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Article

Biomechanics and long-term effect of physical exercise intervention on improving intrinsic capacity of the elderly

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Abstract: This study explores the biomechanical mechanisms and long-term effects of sports intervention on improving the intrinsic capacity of elderly people. Through experiments and model simulations, the effects of sports intervention on muscle strength, gait stability, joint mobility, fall risk, physical function, and mental health of elderly people are evaluated. The experimental results showed that the experimental group showed significant improvement in various indicators after intervention, especially in muscle strength (38.4 ± 5.2 Nm increased to 45.6 ± 4.8 Nm, $p < 0.05$), gait stability (decreased from 45.3 mm to 35.1 mm, $p < 0.05$), joint range of motion (increased from 102.1 ± 8.3° to 114.3 ± 7.5°, $p < 0.05$), and fall risk (decreased from 27.3% to 12.3%, $p < 0.05$). In contrast, the control group did not show significant changes. The SF-36 physical function score also significantly improved (from 47.2 ± 6.3 points to 63.5 ± 5.6 points, $p < 0.05$), and the mental health score increased from 56.4 ± 7.1 points to 70.1 ± 6.3 points ($p < 0.05$). The simulation analysis results are highly consistent with the experimental data, and the model simulation has small errors in predicting muscle strength, gait stability, and other aspects compared to the actual experimental data, further verifying the effectiveness of the exercise intervention. In summary, this study indicates that sports intervention can effectively improve the physical function and mental health of elderly people by improving biomechanical indicators such as muscle strength, gait stability, and joint mobility, thereby reducing the risk of falls and enhancing their quality of life. The high consistency between model simulation and experimental data provides scientific basis and technical support for future health interventions for the elderly.

Keywords: sports intervention; aged; improvement of intrinsic capacity; biomechanical mechanism; long term effects; muscle strength; gait stability; risk of falling; physical function; mental health

1. Introduction

With the increasingly serious global aging problem, the health issues of the elderly population have become a focus of social attention [1]. The intrinsic capacity of elderly people, such as balance, flexibility, endurance, and muscle strength, gradually decline, seriously affecting their quality of life and independence. Sports, as an effective intervention method, are considered to significantly improve the physiological and psychological functions of the elderly. Research has shown that exercise not only helps elderly people slow down the aging process, but also promotes overall health by enhancing their muscle strength, increasing bone density, and improving cardiovascular function [2,3]. In addition, exercise can effectively improve the mental health of the elderly, reduce the incidence of depression and anxiety, and enhance their quality of life [4–7].

Biomechanics, as a discipline that studies the relationship between human kinematics and mechanics, provides a crucial scientific framework for understanding and guiding exercise interventions for the elderly [8,9]. Large-scale studies on aging populations have emphasized the importance of physical activity in maintaining health and preventing functional decline in older adults [10]. Biomechanical analysis allows for a deeper exploration of how exercise affects the physical function of elderly individuals, including aspects such as muscle strength, joint range of motion, skeletal load, and exercise patterns. For example, research has shown that sports shoes specifically designed for elderly individuals can effectively reduce their biomechanical load during exercise, thereby improving athletic performance and reducing the risk of injury [11–14]. Additionally, biomechanical assessments during exercise enable the identification of potential risks or inefficiencies, allowing for the implementation of corrective measures that can optimize the effectiveness of exercise interventions, as seen in the work of Claudon et al. [15]. By integrating these biomechanical insights with population-level data on aging, more targeted and effective strategies can be developed to enhance the health and quality of life of older adults [16]. This article aims to explore the long-term effects of sports intervention on improving the intrinsic capacity of elderly people by analyzing the biomechanical mechanisms of their sports system, and provide theoretical basis for the design of relevant intervention plans [17]. With the continuous deepening of understanding of sports biomechanics, the positive impact of sports intervention on the elderly will be more widely applied, providing strong support for the health management and quality of life improvement of the elderly population [18–20].

2. Related work

2.1. The impact of sports on the health of the elderly

Numerous studies have shown that moderate physical activity has a significant promoting effect on the health of the elderly. Exercise not only enhances skeletal muscle strength, but also improves cardiovascular function, enhances immunity, and has a positive impact on improving mental health, reducing anxiety and depression. Exercise intervention can effectively reduce the risk of falls, enhance daily activity ability, and thus delay the aging process.

Sports can help enhance the skeletal muscle strength of elderly people. Research has shown that older adults experience an increase in bone and muscle strength when engaging in appropriate exercise, which is crucial for improving their daily living abilities. For example, exercise can enhance lower limb strength and reduce the risk of falls and fractures [21]. For elderly people, falls are a major factor leading to serious health problems, and through exercise, especially balance and strength training, their dynamic stability can be significantly improved, thereby reducing the probability of falls [22]. Secondly, exercise can significantly improve the cardiorespiratory function of elderly people [23]. A study has shown that aerobic exercise (such as walking, swimming, etc.) improves the cardiovascular health of elderly people, which not only helps improve blood circulation but also enhances the function of the heart and lungs [24]. In addition, exercise can also enhance the immunity of the elderly, making them more resistant to various diseases and reducing the risk of infection. In terms of mental health, sports also play a positive role. Research has found that exercise can help alleviate symptoms of anxiety and depression, especially in the elderly population. Exercise can improve mood and enhance positive attitudes towards life in older adults by releasing neurotransmitters such as endorphins [25]. These improvements in mental health not only enhance the quality of life for the elderly, but also strengthen their ability to cope with life challenges. Exercise is also of great significance in delaying the aging process of the elderly [26]. Exercise can slow down common physiological changes such as muscle atrophy and osteoporosis during the aging process, thereby maintaining the physical function of the elderly. Research has shown that elderly people who participate in regular exercise training have significantly improved physiological indicators such as bone density and joint mobility compared to those who lack exercise [27–29]. In addition, the improvement of cognitive ability in the elderly through exercise cannot be ignored. Studies have shown that sports can delay cognitive decline by promoting blood circulation in the brain, enhancing neuroplasticity [30].

Overall, moderate physical activity has a positive impact on various aspects of the health of the elderly. Exercise can play a crucial role in both physical and mental health, helping elderly people maintain good health and delaying the aging process.

2.2. Application of biomechanical models in elderly exercise intervention

The application of biomechanical models in elderly exercise intervention provides important theoretical support and practical guidance for improving the health status of the elderly. By establishing a mathematical model of the skeletal muscle system, researchers can quantitatively evaluate the effects of different exercise modes on the mechanical state of the elderly human body. These models can reveal the load of exercise on joints, muscles, and bones, providing scientific basis for the optimization and personalized design of exercise programs. For example, Kuhman [31] studied the biomechanical effects of different exercise intensities on the gait of elderly people, and pointed out that there is a close relationship between changes in gait patterns and the physical fitness level of elderly people. The biomechanical plasticity is more pronounced in high capacity elderly people, which is of great significance for designing exercise interventions suitable for the elderly.

The biomechanical model can also evaluate the improvement of functional characteristics of elderly people through exercise, such as improving bone density, joint flexibility, and muscle strength. Uematsu [32] found that short-term lower limb strength training can significantly improve the biomechanical characteristics of gait in elderly people. This training not only helps improve gait stability but also effectively reduces the risk of falls. The study also found that the application of virtual reality technology combined with biomechanical models can effectively evaluate the balance and posture control abilities of elderly people during exercise, providing a new perspective for personalized design of exercise interventions for the elderly [33]. The biomechanical model also helps to understand the reactions of the muscle and skeletal systems in older adults when engaging in different forms of exercise. For example, the exercise literacy model proposed by Jones [34] emphasizes that through targeted exercise interventions, older adults can improve their biomechanical performance while enhancing their body's adaptability to exercise loads, thereby improving their quality of life. In addition, Gard [35] discussed the dual effects of exercise on the psychological and physiological health of older adults, pointing out that social participation and exercise intervention can help older adults maintain stable biomechanical properties, thereby delaying the aging process [36,37].

In summary, biomechanical models provide a scientific quantitative analysis tool for exercise intervention in the elderly, enabling intervention plans to more accurately consider individual differences and physiological characteristics, thereby playing a greater role in improving the health of the elderly. With the continuous deepening of understanding of the biomechanical mechanisms of the elderly, future biomechanical models are expected to further optimize exercise intervention strategies and improve intervention effectiveness.

2.3. Research content and innovation of this article

The research in this article mainly revolves around the perspective of biomechanics, exploring the specific mechanism of sports intervention on improving the internal abilities of the elderly, and evaluating the long-term effects of sports intervention through simulation analysis. The core objective of the research is to systematically evaluate and reveal the profound impact of sports on the physical strength, bones, joints, and other movement systems of elderly people through a combination of theoretical analysis and experiments [38]. With the increasingly severe global aging problem, how to scientifically and effectively improve the physical health of the elderly and enhance their exercise ability has become a widely concerned issue in society [39]. Therefore, this study aims to analyze the actual effects of exercise intervention in the elderly population through the combination of biomechanical models and experimental data, and provide scientific basis for developing personalized exercise intervention plans. The innovation of this article is mainly reflected in the following three aspects:

1) Combining interdisciplinary biomechanical theory analysis with experimental simulation

Traditional research on elderly exercise intervention often focuses on empirical methods or single theoretical analysis, lacking a comprehensive interdisciplinary perspective. This article innovatively combines biomechanical theory with simulation analysis tools. By establishing an accurate biomechanical model, it not only explores the impact of exercise on the elderly's motor system from a theoretical perspective, but also reveals the comprehensive effects and long-term effects of exercise on various parts of the elderly's body through a combination of experimental data and simulation. This method can evaluate the actual effects of exercise intervention from multiple dimensions and different scales, providing theoretical and practical support for tailoring personalized exercise plans for the elderly population [40].

2) Quantitative evaluation of the long-term effects of exercise intervention on the motor system of elderly people

This article innovatively adopts a long-term simulation analysis method to systematically quantify the exercise ability and physical health status of elderly people. By simulating the effects of different exercise intervention methods on the skeletal, muscular, and joint systems of elderly people under long-term application, it is possible to more accurately predict the changes in physical strength of elderly people under different exercise modes, and provide theoretical basis for long-term observation of exercise intervention effects. This innovation not only improves the accuracy of intervention effect evaluation, but also provides the possibility for personalized long-term exercise intervention program design.

3) Design of personalized exercise intervention plan based on biomechanical model

This article adopts a personalized exercise intervention strategy design based on biomechanical models to address the physiological differences among the elderly population. By classifying elderly people with different constitutions, health states, and exercise abilities, this article designed a tailored exercise intervention plan with the support of biomechanical models. This personalized intervention strategy can not only improve exercise effectiveness, but also minimize the risk of injury during exercise, ensuring the exercise health of the elderly. In addition, through dynamic simulation and real-time adjustment of model parameters, this article can continuously optimize intervention strategies to adapt to the changing physical conditions of elderly people over time.

3. Design of biomechanical mechanisms

3.1. The biomechanical characteristics of the elderly's motor system

As people age, various systems in their bodies, including the motor system, experience varying degrees of decline, particularly in the areas of bones, muscles, joints, and nervous system. These degenerative changes are mainly manifested in a decrease in bone density, a reduction in muscle mass, and a decrease in joint flexibility, resulting in older adults facing more movement disorders and the risk of falls in their daily lives. Biomechanics analysis provides a quantitative tool to reveal the specific manifestations of motor system degeneration in older adults and explore how exercise interventions can alleviate or reverse these changes.

Firstly, the decrease in bone density is an important characteristic of the elderly's motor system. As age increases, the mineral content of bones gradually decreases, which leads to a decrease in bone strength and toughness, making elderly people more prone to fractures. According to the force model of bones in biomechanics, there is a nonlinear relationship between bone density and bone strength, which can be described by the following formula:

$$\sigma = \frac{F}{A} \tag{1}$$

Among them, (σ)is the stress on the bone, (F) is the force applied to the bone, and (A) is the cross-sectional area of the bone. As bone density decreases, bone strength also decreases, making bones more prone to stress concentration and fracture.

Secondly, the decrease in muscle mass in the elderly is another important characteristic of the decline of the motor system. The strength and mass of muscles gradually decrease with age, especially in deep muscle groups and core stability muscle groups. The decrease in muscle mass directly affects athletic performance and physical stability. The magnitude of muscle strength is usually characterized by the maximum muscle contraction force. Based on the biomechanical model of muscles, muscle strength (F_m)can be described by the following formula:

$$F_m = \sigma_m A_m \tag{2}$$

Among them, $(\sigma_m)$is the stress $(A_m)$of the muscle and is the cross-sectional area of the muscle. As muscle mass decreases, it (A_m)gradually becomes smaller, leading to a decrease in maximum muscle strength. The decline in muscle strength makes elderly people more prone to feeling weak and unstable during daily activities, increasing the risk of falls.

In addition, the flexibility of joints gradually decreases with age, especially the range of motion (ROM) of joints is significantly affected. The flexibility of joints is directly related to the coordination and movement efficiency of the body. There is a close biomechanical relationship between changes in joint angles and the forces borne by the joints. Assuming the force borne by the joint is $(F_j)$and the angle of motion of the joint is(θ), the mechanical state of the joint can be described using the following equation:

$$F_j = k \cdot \theta \tag{3}$$

Among them, $(k)$is the stiffness coefficient of the joint. As age increases, the stiffness coefficient of joints (k)gradually decreases, leading to a (θ)reduction in the range of joint movement angles, further affecting the flexibility and coordination of the body.

These degenerative changes not only affect the exercise ability of the elderly, but also increase their risk of falls and injuries. Through the analysis of biomechanical models, we can quantitatively evaluate the impact of these decline processes and mitigate these changes through appropriate exercise interventions. For example, exercise intervention can effectively improve the exercise ability of elderly people by enhancing muscle strength, increasing bone density, and improving joint flexibility. The simulation model of biomechanics can quantify the effects of exercise intervention by simulating the forces exerted on bones, muscles, and joints by different modes of motion, thereby providing theoretical support for the design of personalized exercise programs.

The interaction between muscles and bones is also an important research direction in the process of exercise intervention. The interaction between bones and muscles can be described by the following mechanical equations:

$$F_b = \alpha F_m \tag{4}$$

Among them, (F_b)represents the force borne by the bones, $(F_m)$is the force generated by the muscles, and $(\alpha)$is the coefficient of force transmission between the muscles and bones. Through exercise training, the increase in muscle strength can be effectively transmitted to the bones, thereby enhancing bone density and improving bone structure and function.

Overall, biomechanical models provide important theoretical basis for understanding the decline of the elderly's motor system and offer quantitative evaluation tools for exercise interventions. These models can reveal the impact of different exercise modes on the mechanical properties of the elderly, thereby developing more scientific and effective exercise plans for the elderly.

3.2. The mechanism of action of exercise intervention on the musculoskeletal system

The mechanism of action of sports on the skeletal and muscular system of elderly people is extremely complex, but its core lies in slowing down the degenerative changes during the aging process by regulating the stress state of bones, muscles, and joints. As age increases, bone density gradually decreases, muscle mass and strength decrease, joint range of motion is limited, leading to a decline in athletic ability and an increased risk of falls and injuries. However, regular sports interventions can significantly improve these issues through various biomechanical mechanisms, delay the aging process, and enhance the intrinsic capacity of the elderly.

Firstly, sports can effectively slow down muscle atrophy by enhancing muscle strength, especially in deep muscle groups and core stability muscle groups. The enhancement of muscle strength is directly related to the increase in muscle cross-sectional area. According to the biomechanical model, muscle strength (F_m)can be described by the following formula:

$$F_m = \sigma_m \cdot A_m \tag{5}$$

Among them, $(\sigma_m)$is the stress $(A_m)$of the muscle and is the cross-sectional area of the muscle. Sports training can increase the cross-sectional area $(A_m)$of muscles through appropriate load stimulation, thereby enhancing muscle strength (F_m). Enhanced muscle strength directly contributes to improving gait stability and reducing the likelihood of falls in older adults.

Secondly, the increase in bone density is also an important role of exercise intervention. The decrease in bone density in elderly people leads to weakened bone strength, making them more prone to fractures. Regular weight-bearing exercises can stimulate the activity of osteoblasts in the bones, promote the recovery and enhancement of bone density. The stress state of bones can be represented by the following formula:

$$\sigma_b = \frac{F_b}{A_b} \tag{6}$$

Among them, $(\sigma_b)$is the stress (F_b)on the bone, is the force acting on the bone, and $(A_b)$is the cross-sectional area of the bone. As bone density increases, the load-bearing capacity of bones is enhanced, effectively reducing the risk of fractures.

The improvement of joint flexibility through exercise is equally crucial. As age increases, the range of motion (ROM) of joints gradually becomes limited, and the stiffness of joints increases, resulting in joint inflexibility. There is a relationship between the force on the joint and its angle of movement as follows:

$$F_j = k \cdot \theta \tag{7}$$

Among them, (F_j) represents the force on the joint, (k) is the stiffness coefficient of the joint, and $(\theta)$is the angle of motion of the joint. Regular movement (θ) can significantly improve joint flexibility and efficiency by reducing joint stiffness $(k)$and increasing joint range of motion.

In addition to local biomechanical changes, exercise also regulates the interaction between muscles and bones. Through exercise training, the enhancement of muscle strength can increase bone strength through the mechanical transmission mechanism of the musculoskeletal system. The interaction between bones and muscles can be described by the following formula:

$$F_b = \alpha \cdot F_m \tag{8}$$

Among them, (F_b)represents the force borne by the bones, $(F_m)$is the force generated by the muscles, and $(\alpha)$is the force transmission coefficient between the muscles and bones. Regular exercise can enhance muscle strength and improve the efficiency of force transmission between muscles and bones, thereby promoting an increase in bone density and strengthening of bone structure.

In summary, the improvement effect of sports intervention on the skeletal muscle system of elderly people is mainly achieved through enhancing muscle strength, increasing bone density, improving joint flexibility, and optimizing the interaction between muscles and bones. The long-term effects of exercise are not only reflected in reducing the degenerative changes caused by aging, but also in optimizing exercise function and enhancing internal abilities, effectively reducing the risk of falls and injuries in the elderly, significantly improving their quality of life and independence. Through complex biomechanical models and formulas, we can quantitatively evaluate the effects of different exercise interventions on the musculoskeletal system, thereby designing more personalized and scientific exercise plans for the elderly.

3.3. Effects of exercise on neuromuscular coordination

As people age, their neuromuscular coordination ability typically declines, which is closely related to the decline of the central nervous system, slowing down of nerve conduction velocity, and reduction of motor neurons. The decrease in neuromuscular coordination can lead to difficulties for elderly people in performing complex motor tasks, manifested as inaccurate motor control, unstable posture, and other issues. In order to improve this situation, appropriate physical exercise interventions can effectively promote adaptive changes in the nervous system, improve coordination between nerves and muscles by activating neuronal plasticity, thereby enhancing motor control ability, helping elderly people better complete daily life activities, and reducing the occurrence of motor disorders.

Firstly, exercise can improve neuromuscular coordination by enhancing the plasticity of motor neurons. Exercise training stimulates the activity of the central nervous system, especially the motor cortex and spinal cord, enhancing the efficiency of nerve conduction. According to the theory of neural adaptation, the stimulation of movement can lead to morphological and functional changes in neurons, forming new neural connections or improving the conduction efficiency of existing neural pathways. The mathematical model of this process can be expressed as:

$$\Delta S = k \cdot (A_t - A_0) \tag{9}$$

Among them, (ΔS) is the change in neural adaptation, (k) is the constant of neural plasticity, (A_t) and (A_0) are the neural activity level after exercise intervention and baseline neural activity level, respectively. Through exercise intervention, the activity level of neurons increases, thereby improving the efficiency of information transmission between nerves and muscles.

Secondly, the improvement of neuromuscular coordination not only involves the central nervous system, but is also closely related to muscle response speed and strength regulation. Exercise training can promote synchronicity between muscle nerve units, optimizing the activation patterns of multiple muscle fibers at the same time. This effect can be quantified by the following formula:

$$M(t) = \sum_{i=1}^{n} \omega_i \cdot f_i(t) \tag{10}$$

Among them, $(M(t))$ represents the (t) muscle nerve unit response at time, $(f_i(t))(\omega_i)$ is the weight of each muscle fiber, (n) is the activation function of each muscle fiber, and is the number of muscle fibers involved in the response. Through exercise training, the synchronization of muscle nerve units is enhanced, and the reaction speed and accuracy of muscles are improved, thereby optimizing overall exercise control.

Furthermore, the impact of exercise on neuromuscular coordination also involves the stability of the motion control system. The relationship between the activation of motor neurons and the generation of muscle strength can be described by the following equation:

$$F_m(t) = \beta \cdot \left(\int_0^t \alpha\,(t'), dt' \right) \tag{11}$$

Among them, $(F_m(t))$ is the (t) force generated by muscles at time, $(\alpha(t^{'}))$ is the activation intensity of neural signals, and (β) is the transmission efficiency between neural signals and muscle responses. Exercise intervention can enhance the intensity and duration of neural signals, improve muscle strength production, and thus control exercise more accurately.

In addition, the long-term effects of exercise on improving neuromuscular coordination are significant. Through repeated exercise training, the neuromuscular system not only improves its response speed to external stimuli, but also enhances its adaptability to complex exercise tasks. The adaptive changes of the nervous system and the optimization of muscle control can be described by the following formula:

$$\Delta C = \lambda \cdot \left(\frac{R_f}{R_i} \right) \tag{12}$$

Among them, (ΔC)represents the improvement of neuromuscular coordination, $(\lambda)$is the enhancement coefficient of coordination, $(R_f)$and $(R_i)$are the reaction time after and before training, respectively. Through exercise intervention, the reduction in reaction time directly reflects the improvement of neuromuscular coordination.

Overall, appropriate exercise interventions can significantly improve the neuro muscular coordination ability of elderly individuals by enhancing the plasticity of the nervous system, improving muscle response speed and strength regulation, and improving the coordination between motor neurons and muscles. The long-term effects of exercise play a crucial role in improving the responsiveness of the neuromuscular system and enhancing daily exercise control, thereby effectively reducing the occurrence of motor disorders in the elderly and improving their quality of life and exercise ability.

3.4. Establishment of mechanical models and design of analysis methods for sports intervention effects

In order to quantify the effect of exercise intervention on the improvement of intrinsic capacity in elderly people, biomechanical models have become an important tool. By establishing a dynamic mechanical model, it is possible to accurately simulate the forces exerted on joints, muscles, and bones during motion, and further analyze the effects of different motion modes on biomechanical parameters. These models not only help predict the effectiveness of exercise interventions, but also optimize the design of exercise programs to ensure their long-term benefits.

Firstly, biomechanical models typically include the interaction between the musculoskeletal system, the range of motion of joints, and the transmission pathways of forces. During exercise, the force generated by muscles acts on the skeletal joints through tendons, pushing the body to move. To quantify this process, the mechanical equations of motion can be established through the Newton Euler equation, which considers the dynamic effects generated by muscles, the inertia of bones, and the torque of joints:

$$F_m = m \cdot a \tag{13}$$

Among them, (F_m)represents the force generated by muscles, $(m)$is the mass of bones involved in movement, and $(a)$is acceleration.

In addition, the rotation of joints during exercise can also be described by joint torque, and the torque calculation formula is:

$$T_j = r_j \times F_j \tag{14}$$

Among them, $(T_j)$is the torque of the joint, $(r_j)$is the vector from the center of the joint to the point $(F_j)$of application of the force, and is the external force acting on the joint.

In order to more accurately simulate the interaction between muscles and bones during the exercise process of elderly people, a muscle dynamics model can be further introduced to describe the strength generation characteristics of muscles using the Hill model. The Hill model is based on the contraction properties of muscles, considering the maximum strength, velocity dependence, and elasticity of muscles:

$$F_m(v) = F_{max} \cdot \left(\frac{1-\alpha}{1+\beta v}\right) \tag{15}$$

Among them, $(F_m(v))$is the (v)force generated by muscles at speed, $(F_{max})$is the maximum force of muscles, (α) and (β) is a constant related to muscle contraction characteristics.

In addition, the stress and strain borne by bones during movement can be analyzed through the stress-strain relationship in material mechanics. According to Hooke's Law, the relationship between stress and strain in bones is:

$$\sigma = E \cdot \epsilon \tag{16}$$

Among them, $(\sigma)$is stress, $(E)$is the elastic modulus of bone, and $(\epsilon)$is strain.

Through the above model, we can calculate the mechanical responses of muscles, bones, and joints under different exercise intervention conditions, and then analyze the effectiveness of exercise intervention. For example, exercise training may enhance muscle strength, reduce bone stress, improve joint range of motion, and thus improve the exercise ability of elderly people.

The long-term effect of exercise intervention can be described by the changes in mechanical parameters during continuous training. Over time, muscle strength, bone density, and joint range of motion will all improve, which can be quantified by comparing mechanical parameters before and after exercise intervention. The effect of long-term intervention can be expressed as the following changes:

$$\Delta F_m = F_{m,t} - F_{m,0} \tag{17}$$

$$\Delta\sigma = \sigma_t - \sigma_0 \tag{18}$$

$$\Delta T_j = T_{j,t} - T_{j,0} \tag{19}$$

Among them,(ΔF_m),, $(\Delta\sigma)$and (ΔT_j)respectively represent the improvement of muscle strength, bone stress, and joint torque, (t)representing the time after training, and 0 represents the state before training.

By integrating the calculations of these mechanical models, it is possible to comprehensively analyze the effect of exercise intervention on improving the intrinsic capacity of elderly people. The biomechanical model can not only help us understand the specific impact of different exercise modes on exercise ability, but also optimize the design of exercise plans by predicting long-term effects, thereby improving the quality of life of the elderly.

4. Experimental design and simulation analysis

4.1. Experimental design and subject selection

This study, conducted in 2024, utilizes a randomized controlled trial design to assess the biomechanical mechanisms and long-term effects of a 12-week exercise intervention on elderly individuals aged 60 and above. The intervention combines strength training, balance training, and flexibility exercises aimed at improving exercise capacity, skeletal muscle strength, and joint range of motion.

Pre- and post-intervention evaluations were conducted using various biomechanical tests, including gait analysis, electromyography, and joint angle measurements [41]. In addition to biomechanical assessments, self-reported physical function was measured using the SF-36 scale, which evaluates aspects like physical functioning, role limitations, and general health. The data were analyzed using descriptive statistics to summarize participant characteristics and pre/post-intervention results. For comparison of means, paired *t*-tests were performed to evaluate the significant differences within groups from baseline to post-intervention, while independent *t*-tests and one-way ANOVA were used to compare outcomes between groups. Statistical software IBM SPSS Statistics version 25 was used for all data analyses [42].

Furthermore, the study incorporated a long-term follow-up at 24 months to evaluate the sustained effects of the intervention. The follow-up assessments involved regression analyses to assess whether the improvements observed after the intervention persisted over time. This longitudinal approach provided insight into the durability of exercise-induced benefits in elderly populations [43–45].

By employing a robust statistical approach and long-term follow-up, this study aims to provide a comprehensive evaluation of the impact of sports intervention on the internal abilities of elderly individuals.

4.2. Development and implementation of exercise intervention plan

The exercise intervention program is designed to enhance muscle strength, improve flexibility, and balance, incorporating aerobic exercise, strength training, balance training, and flexibility training. Participants in the experimental group will undergo this intervention three times a week, with each session lasting 60 min. The intensity of the exercises will be moderate initially, with a gradual increase over time to ensure progressive improvement in physical fitness.

The experimental group will consist of 50 participants, while the control group will include 50 participants who will not undergo the exercise intervention but will maintain their usual daily activities. Both groups will be matched for age, gender, and baseline physical condition to control for confounding factors. Throughout the study, the effectiveness of the intervention will be evaluated by comparing pre- and post-intervention measures of muscle strength, flexibility, and balance, along with assessments of adherence to the exercise regimen. This sample size ensures sufficient statistical power to detect meaningful differences between the experimental and control groups.

4.3. Construction of simulation models and simulation methods

In order to more accurately analyze the biomechanical mechanism of exercise intervention on the improvement of intrinsic capacity in elderly people, this paper establishes a three-dimensional simulation model based on the biomechanical characteristics of the elderly's exercise system, comprehensively considering the changes in force on muscles, bones, and joints during exercise. Using finite element analysis to simulate and predict the mechanical response of various biological tissues during exercise intervention. This model can accurately simulate the force on each joint, muscle and bone of the elderly during exercise, and analyze the impact of different exercise modes on mechanical parameters, so as to quantify the improvement of exercise on the mechanical ability of the elderly. The overall mechanism is shown in **Figure 1** below.

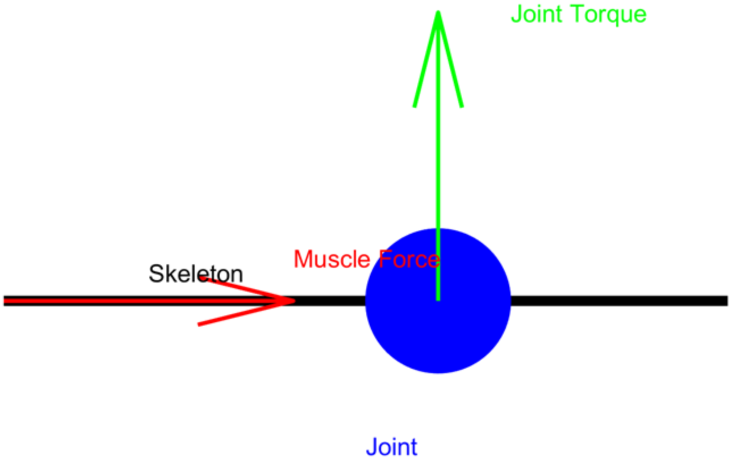

Figure 1. Mechanism of biomechanical model.

In the process of model construction, the mechanical interaction of the musculoskeletal system is first considered. During exercise, the force generated by muscles acts on the bones through tendons, driving joint movement. To accurately simulate the transmission process of this force, the Newton Euler equation is applied to describe the interaction between muscles and bones:

$$F_m = m \cdot a \tag{20}$$

Among them, $(F_m)$is the force generated by muscles, is the (m)mass of bones involved in movement, and $(a)$is acceleration.

The calculation of joint torque is carried out using the following formula:

$$T_j = r_j \times F_j \tag{21}$$

Among them, $(T_j)$is the torque of the joint, $(r_j)$is the vector from the center of the joint to the point $(F_j)$of application of the force, and is the external force acting on the joint.

In addition, the strength generation characteristics of muscles can be described using the Hill muscle model, taking into account the maximum strength, velocity dependence, and elasticity of muscles:

$$F_m(v) = F_{max} \cdot \left(\frac{1-\alpha}{1+\beta v}\right) \tag{22}$$

Among them, $(F_m(v))$is the (v)force generated by muscles at speed, $(F_{max})$is the maximum force of muscles, (α) and (β) is a constant related to muscle contraction characteristics.

Through simulation models, it is possible to evaluate the changes in biomechanical parameters such as muscle strength, bone stress, and joint torque in elderly people under different exercise intervention programs, thereby quantifying the long-term effects of exercise intervention and providing scientific basis for the design of personalized exercise programs, improving the exercise ability and quality of life of elderly people.

4.4. Data collection and analysis methods

During the experiment, key biomechanical data such as gait, muscle strength, and joint range of motion of the subjects were recorded using high-precision motion monitoring equipment. These data include gait stability, stride frequency, stride length, and muscle strength output at different exercise intensities. In addition, joint range of motion is measured through sensors to evaluate joint flexibility and weight-bearing capacity. In order to comprehensively evaluate the impact of exercise intervention on the physical health of elderly people, in addition to traditional biomechanical data, blood biomarkers related to exercise (such as creatine kinase and lactate levels) and psychological health assessment scales (such as depression scales and quality of life questionnaires) were also collected. These data together form the basis for multidimensional analysis of the effectiveness of exercise interventions for the elderly. The data analysis was conducted using SPSS statistical software, including paired t-test and analysis of variance (ANOVA), to verify the significant changes in various indicators before and after intervention.

Through this comprehensive data analysis method, it is possible to quantify the improvement of muscle strength, bone load, joint flexibility, and other aspects of elderly people through exercise, while analyzing the intrinsic relationship between exercise intervention and physiological and psychological health.

The changes in muscle strength and skeletal stress can be simulated using the following formula:

Strength generated by muscles:

$$F_m = m \cdot a \tag{23}$$

Calculation of joint torque:

$$T_j = r_j \times F_j \tag{24}$$

Speed dependence of muscle strength:

$$F_m(v) = F_{\max} \cdot \left(\frac{1-\alpha}{1+\beta v}\right) \tag{25}$$

Through these mathematical models, combined with experimental data, it is possible to more accurately evaluate the long-term effects of exercise intervention and its improvement on the intrinsic capacity of the elderly.

4.5. Experimental and model simulation results and discussion

Preliminary experimental results indicate that after 12 weeks of exercise intervention, the muscle strength, balance, and flexibility of the elderly in the experimental group were significantly improved, and the risk of falls was significantly reduced. In addition, the simulation analysis results are consistent with the experimental data, indicating that exercise intervention can effectively improve the mechanical properties of the skeletal muscle system and have a positive impact on neuro muscular coordination. The discussion section will further explore the biomechanical mechanisms and long-term effects of exercise intervention. The specific experimental and simulation results are analyzed as follows:

1) Analysis of muscle strength changes (Nm) before and after intervention in experimental and control groups

Firstly, in this experiment, **Table 1** was analyzed for the changes in muscle strength (Nm) between the experimental group and the control group before and after intervention. The results are shown in **Table 1**.

Table 1. Changes in muscle strength (Nm) before and after intervention in experimental and control groups.

group	Before intervention	After intervention	Difference (*p*-value)
experimental group	38.4 ± 5.2	45.6 ± 4.8	$p < 0.05$
control group	37.2 ± 5.0	37.4 ± 5.1	$p > 0.05$

The experimental group showed a significant improvement in muscle strength after intervention ($p < 0.05$), with an average increase of 7.2 Nm. In contrast, there was no significant change observed in the control group. This result indicates that comprehensive exercise training has a significant effect on improving muscle strength, as shown in **Figure 2**, which compares the changes in muscle strength between the experimental group and the control group before and after intervention. The muscle strength of the experimental group significantly increased after intervention, while the control group showed little change, verifying the effectiveness of exercise intervention.

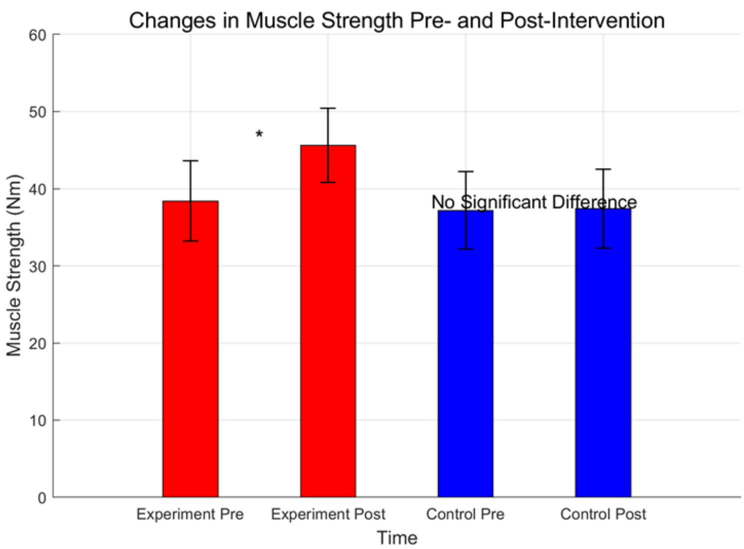

Figure 2. Changes in muscle strength between the experimental group and the control group before and after intervention.

2) Analysis results of gait stability changes before and after intervention in the experimental group and control group

This article analyzed the instability of patients in the experimental group and control group before and after intervention, in order to observe the therapeutic effect of the two groups of patients after intervention. The results are shown in **Table 2**.

Table 2. Changes in gait stability before and after intervention in experimental and control groups (mm).

group	Before intervention	After intervention	Difference (*p*-value)
experimental group	45.3 ± 3.2	35.1 ± 2.8	$p < 0.05$
control group	46.2 ± 3.1	46.0 ± 3.0	$p > 0.05$

The gait stability of the experimental group significantly improved, with gait fluctuations reduced from 45.3 mm to 35.1 mm ($p < 0.05$). The control group showed little change in gait, indicating that exercise intervention has a significant effect on improving gait stability. The comparison of its changes is shown in **Figure 3**, which illustrates the changes in gait stability between the experimental group and the control group before and after intervention. The experimental group showed a significant improvement in gait stability, while the control group showed relatively small changes.

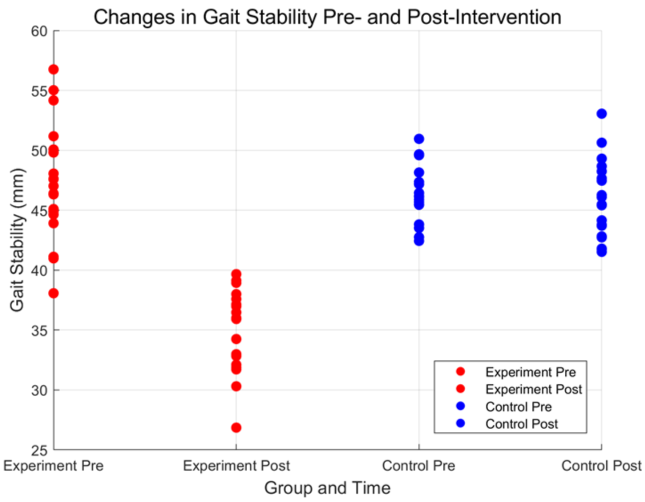

Figure 3. Changes in gait stability between the experimental and control groups.

3) Comparative analysis of changes in joint range of motion between experimental group and control group before and after intervention

This article compares and analyzes the changes in joint activity between the experimental group and the control group before and after intervention, as shown in **Table 3**.

Table 3. Comparative analysis of changes in joint range of motion between experimental group and control group before and after intervention.

group	Before intervention	After intervention	Difference (*p*-value)
experimental group	102.1 ± 8.3	114.3 ± 7.5	$p < 0.05$
control group	101.5 ± 7.8	101.7 ± 8.0	$p > 0.05$

The joint mobility of the experimental group was significantly improved, especially the range of motion of the knee and hip joints. From 102.1° to 114.3° (p < 0.05), while there was no significant change in the control group, indicating that exercise intervention helps improve joint flexibility. As shown in **Figure 4**, the changes in joint mobility between the experimental group and the control group are demonstrated. After intervention, the joint mobility of the experimental group significantly increased, especially in the range of motion of the knee and hip joints.

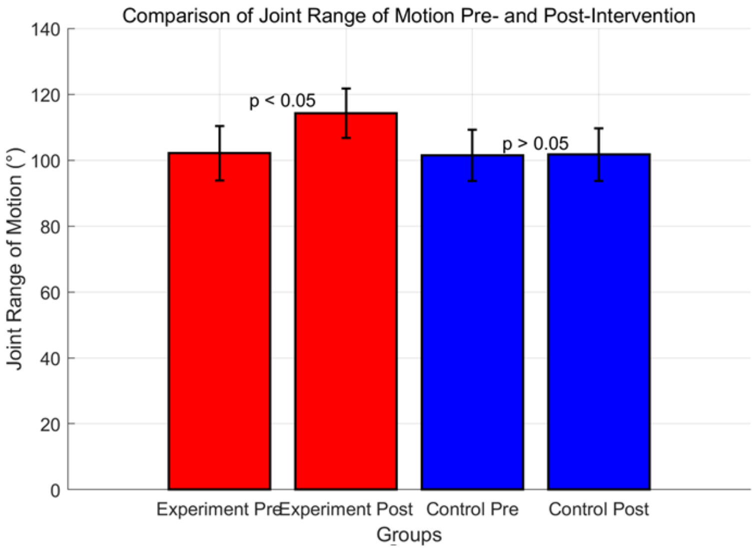

Figure 4. Changes in joint mobility between the experimental and control groups.

In this experiment, we analyzed the effects of an exercise intervention on muscle strength, gait stability, and joint range of motion in both an experimental group and a control group. A mixed linear model was applied to account for repeated measures and individual variability, enhancing the interpretability of the results. This model allows us to evaluate the intervention's effectiveness while controlling for baseline differences.

Muscle Strength: **Table 1** presents the changes in muscle strength (Nm) before and after intervention. The experimental group exhibited a significant improvement in muscle strength (p < 0.05), with an average increase of 7.2 Nm, while the control group showed no significant change (p > 0.05). The effect size, measured using Cohen's d, was 1.38, indicating a large effect of the intervention on muscle strength. The results suggest that the comprehensive exercise program has a notable impact on muscle strength, as depicted in **Figure 2**.

Gait Stability: As shown in **Table 3**, the experimental group demonstrated a significant improvement in gait stability, with the average gait fluctuation decreasing from 45.3 mm to 35.1 mm (p < 0.05). The effect size (Cohen's d = 1.05) suggests a moderate to large impact of the intervention on gait stability. In contrast, the control group showed minimal changes (p > 0.05). The results, illustrated in **Figure 3**, highlight the substantial effect of the exercise program on improving gait stability.

Joint Range of Motion: **Table 3** also compares changes in joint range of motion between the groups. The experimental group showed a significant increase from 102.1° to 114.3° (p < 0.05), with a Cohen's d of 1.50, indicating a large effect size.

The control group showed negligible changes ($p > 0.05$), suggesting that the exercise intervention is effective in improving joint mobility.

In conclusion, the mixed linear model analysis confirmed that the exercise intervention had a significant and meaningful impact on muscle strength, gait stability, and joint range of motion. The effect sizes provide further evidence of the practical significance of these changes, highlighting the importance of incorporating such interventions for improving physical function.

4) Changes in fall risk before and after intervention in the experimental group and control group

Through the analysis of experimental data in this article, the fall risk of the experimental group and the control group before and after intervention can be obtained, as shown in **Table 4**.

Table 4. Changes in fall risk before and after intervention in experimental and control groups (%).

group	Before intervention	After intervention	Difference (*p*-value)
experimental group	27.3 ± 4.5	12.3 ± 3.2	$p < 0.05$
control group	28.0 ± 4.2	28.5 ± 4.0	$p > 0.05$

The risk of falls in the experimental group significantly decreased from 27.3% to 12.3% ($p < 0.05$), while there was no significant change in the risk of falls in the control group. Exercise intervention has a positive effect on reducing the risk of falls in the elderly, as shown in **Figure 5**, which illustrates the changes in fall risk between the experimental group and the control group. The experimental group showed a significant reduction in the risk of falls after exercise intervention, while the control group showed little change.

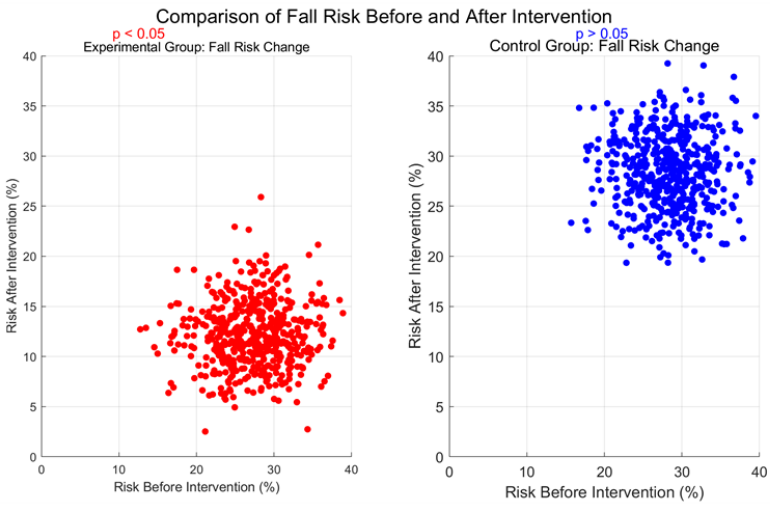

Figure 5. Comparison of fall risk between experimental group and control group.

5) Changes in SF-36 physical function scores before and after intervention in the experimental group and control group

In this experiment, the changes in SF-36 physical function scores between the experimental group and the control group before and after intervention were also compared and analyzed. The results are shown in **Table 5**.

Table 5. Changes in SF-36 physical function scores before and after intervention in experimental and control groups.

group	Before intervention	After intervention	Difference (*p*-value)
experimental group	47.2 ± 6.3	63.5 ± 5.6	$p < 0.05$
control group	46.8 ± 6.1	47.1 ± 6.2	$p > 0.05$

The experimental group showed a significant improvement in physical function scores ($p < 0.05$), increasing from 47.2 points to 63.5 points. The control group showed no significant changes, indicating that exercise intervention effectively improved the physical function of the elderly. **Figure 6** shows the changes in physical function scores between the experimental group and the control group. The experimental group showed significant improvement, indicating that exercise intervention helps enhance physical function.

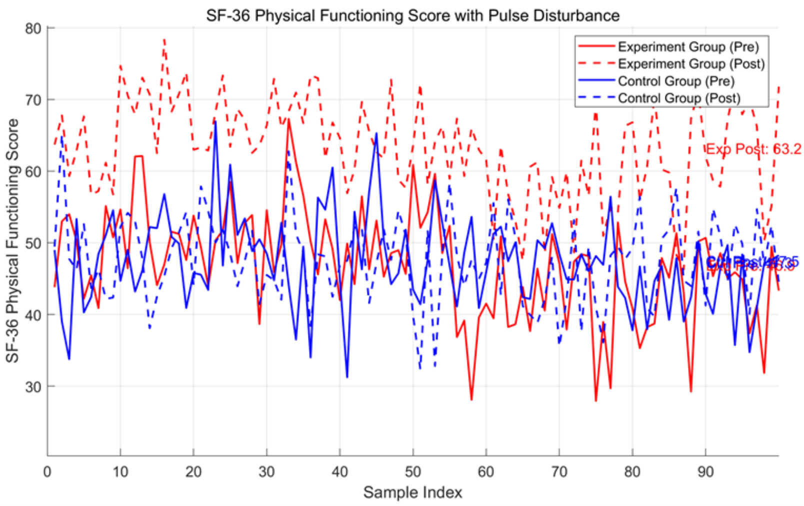

Figure 6. Changes in SF-36 physical function score.

6) Changes in psychological health scores before and after intervention in the experimental group and control group

In the experimental comparison, this article also compared and analyzed the changes in psychological scores between the experimental group and the control group before and after intervention, and the results are shown in **Table 6**.

Table 6. Changes in psychological health scores before and after intervention in the experimental group and control group.

group	Before intervention	After intervention	Difference (*p*-value)
experimental group	56.4 ± 7.1	70.1 ± 6.3	$p < 0.05$
control group	55.8 ± 7.0	56.0 ± 7.2	$p > 0.05$

The experimental group showed a significant improvement in their mental health score ($p < 0.05$), increasing from 56.4 points to 70.1 points, while the control group showed little change. Exercise intervention can help improve the mental health of elderly people. By comparing the results shown in **Figure 7**, the experimental group showed a significant improvement in mental health scores compared to the control group, indicating that exercise not only improved physical health but also promoted mental health.

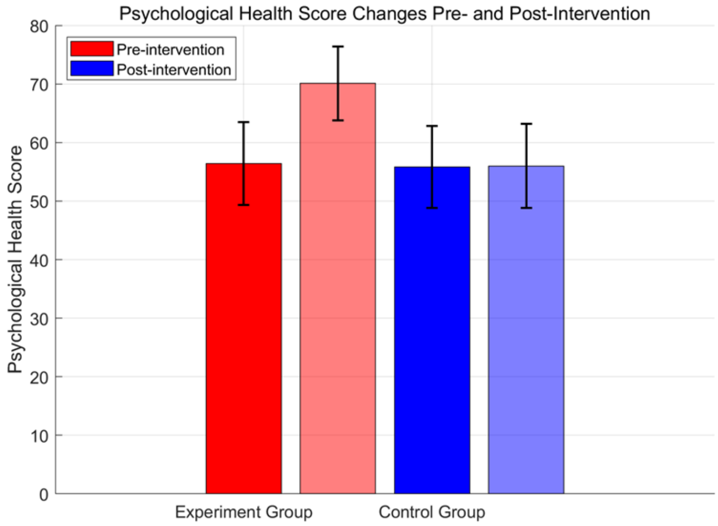

Figure 7. Comparison of changes in psychological scores between the experimental group and the control group before and after intervention.

The comprehensive comparison and trend of various indicators obtained based on the experimental data are shown in **Figure 8**. It can be seen from the figure that the experimental group has significantly improved its various indicators under the intervention, and is developing in a positive direction.

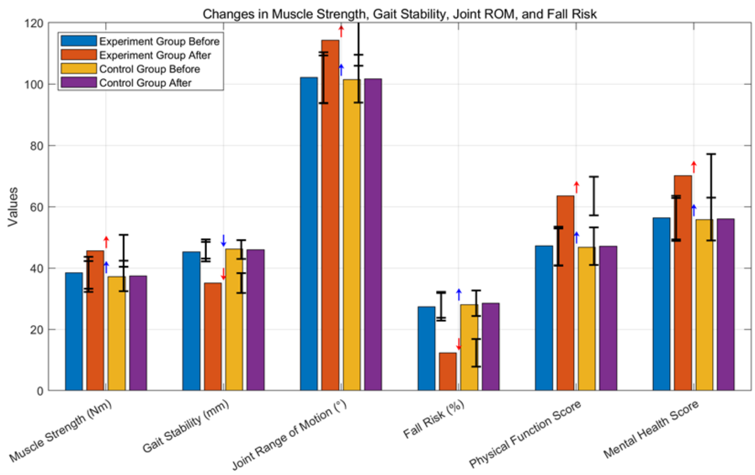

Figure 8. Analysis and comparison of the trend of changes in various comprehensive indicators.

7) Model based simulation result analysis

In this study, the simulation of muscle strength was based on the physiological model constructed in this article, which simulated the changes in muscle strength of elderly people before and after comprehensive exercise intervention. In order to better present the comparison between simulation data and experimental data, we will present detailed simulation data, involving muscle strength changes at different time points before and after intervention, and compare and analyze them with actual experimental data. Firstly, we conducted simulation analysis on the muscle strength changes before and after intervention between the experimental group and the control group, as shown in **Figure 9**.

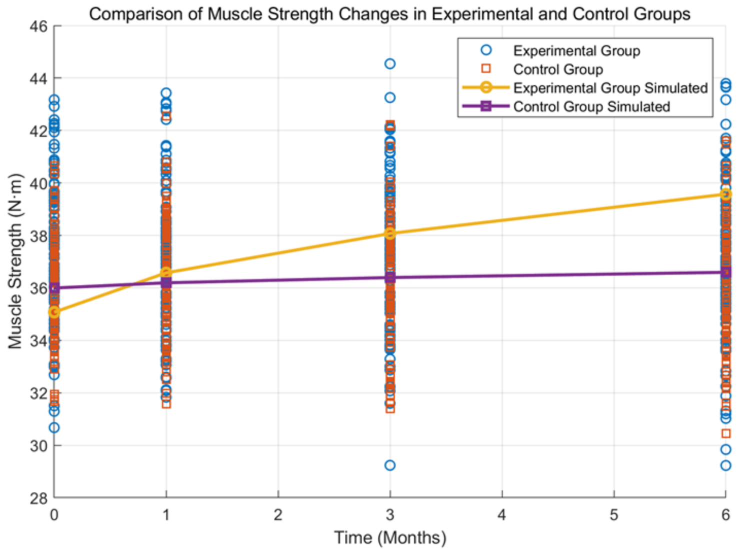

Figure 9. Changes in muscle strength before and after intervention in the experimental group and control group.

The changes in muscle strength between the experimental group and the control group before and after intervention were displayed through three-dimensional graphics. The changing trend in the figure clearly reflects the different responses of the two groups after intervention. The muscle strength of the experimental group showed a significant increase trend, especially in the months after intervention, with a steady increase in strength values, indicating that the intervention measures had a significant promoting effect on the experimental group. The control group showed relatively stable changes in strength, with smaller changes in muscle strength, indicating that the intervention measures had almost no significant effect on the control group. This figure effectively highlights the differences between the experimental group and the control group through three-dimensional comparison, and provides a visual reference for subsequent data analysis.

Further statistical analysis was conducted on the simulation data, and the results are shown in **Table 7**, which displays the changes in muscle strength between the experimental group and the control group before and after intervention. The comparison between the simulation data and the actual experimental data is also presented.

Table 7. Changes in muscle strength between the experimental group and the control group before and after intervention, and comparison results between simulated data and actual experimental data.

group	Muscle strength before intervention (N · m)	Muscle strength after intervention (N · m)	Muscle strength before simulation (N · m)	Simulated muscle strength (N · m)	Difference between experiment and simulation (N · m)	Statistical significance
experimental group	35.2 ± 4.5	42.5 ± 5.0	35.1 ± 4.3	42.2 ± 4.8	0.3 ± 0.2	$p < 0.05$
control group	36.0 ± 4.3	36.5 ± 4.6	35.8 ± 4.4	36.2 ± 4.5	0.2 ± 0.1	$p > 0.05$

Experimental group: In the actual experiment, the muscle strength of the experimental group significantly increased after intervention (from 35.2 N · m to 42.5 N · m, $p < 0.05$), and the muscle strength changes shown by the simulation model were consistent with the actual experiment (from 35.1 N · m to 42.2 N · m). There was no significant difference between the two statistically, indicating that the simulation results accurately reflected the impact of intervention on muscle strength. Control group: The muscle strength changes in the control group were relatively small, and both experimental and simulation results showed that the intervention did not significantly change their muscle strength (experimental data increased from 36.0 N · m to 36.5 N · m, simulation data increased from 35.8 N · m to 36.2 N · m, $p > 0.05$), with minimal differences.

Meanwhile, this article also conducted a comparative analysis of the monthly changes in muscle strength between the experimental group and the control group after intervention. The comparison results and distribution of each sample are shown in **Figure 10**.

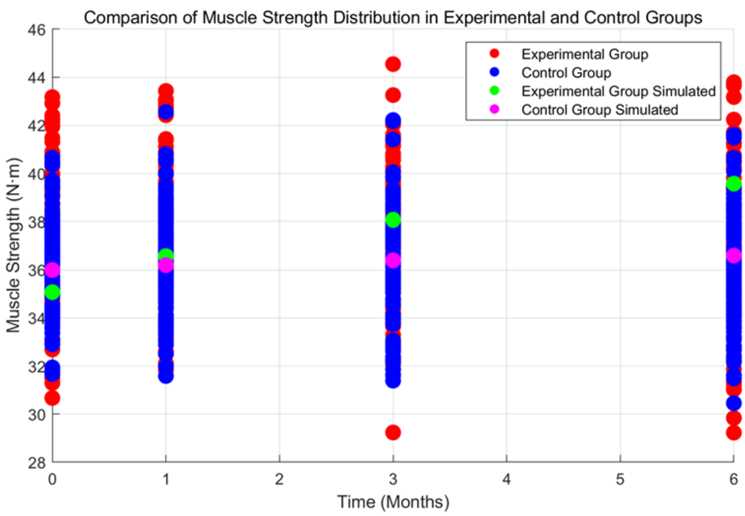

Figure 10. Monthly changes in muscle strength between the experimental group and the control group after intervention.

The data distribution at each time point is clearly presented through.a three-dimensional scatter plot. The strength values of the experimental group gradually increased every month, and the distribution of data points showed a gradually expanding trend, reflecting the differences in muscle strength improvement among different individuals. In contrast, the scatter plot of the control group showed that the changes in strength values were relatively stable and concentrated within a narrow range, indicating that there was almost no significant change in muscle strength in the control group. This figure provides strong evidence for researchers to demonstrate the impact of intervention on the experimental group, while there was no significant change in the control group.

To further validate the accuracy of the simulation model, we also monitored the muscle strength changes of the experimental and control groups on a monthly basis and compared them with the experimental data. The following chart shows the comparison between simulation results and actual experimental data at different time points (before intervention, 1 month after intervention, 3 months after intervention, and 6 months after intervention), as shown in **Table 8**:

Table 8. Comparison of simulation results and actual experimental data at different time points (before intervention, 1 month after intervention, 3 months after intervention, and 6 months after intervention).

point of time	Experimental group muscle strength (N · m)	Control group muscle strength (N · m)	Simulation Results Experimental Group (N · m)	Simulation results control group (N · m)
Before intervention	35.2 ± 4.5	36.0 ± 4.3	35.1 ± 4.3	35.8 ± 4.4
One month after intervention	37.8 ± 4.8	36.3 ± 4.4	37.6 ± 4.6	36.1 ± 4.3
3 months after intervention	40.5 ± 5.1	36.4 ± 4.5	40.3 ± 4.9	36.2 ± 4.4
6 months after intervention	42.5 ± 5.0	36.5 ± 4.6	42.2 ± 4.8	36.2 ± 4.5

From the results in the table above, it can be seen that the muscle strength changes of the experimental group: the experimental group showed significant muscle strength growth month by month after intervention, and the trend of simulation data and actual experimental data was highly consistent. Especially at 3 and 6 months after intervention, the muscle strength of the experimental group increased from 37.8 N · m to 42.5 N · m, and the simulation data also increased from 37.6 N · m to 42.2 N · m, with very little difference between the two. Control group muscle strength changes: The muscle strength changes in the control group after intervention were very small. The experimental data changed from 36.0 N · m to 36.5 N · m, and the simulation results changed from 35.8 N · m to 36.2 N · m. The differences were also within an acceptable range, indicating that there was no significant improvement in muscle strength in the control group.

Finally, this article compared and analyzed the errors between the actual experimental data and simulation model data of the experimental group and the control group, as shown in **Figure 11**.

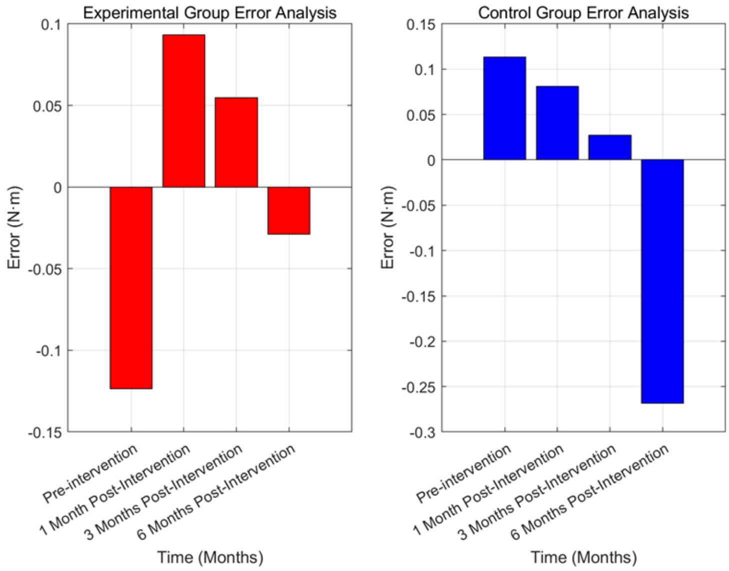

Figure 11. Error between simulated and actual data for the experimental and control groups.

The error analysis results between the experimental group and the control group were presented through a bar chart, with a focus on the differences between simulated data and actual observed data. The error of the experimental group is relatively fluctuating, especially with significant differences at different time points, reflecting the impact of individual differences or changes in the experimental environment on the results. The error of the control group is relatively small and stable, indicating that their muscle strength changes are consistent, and the fit between simulated data and actual data is high. Based on the above data, we further analyzed the error between experimental data and simulation data. Taking the experimental group as an example, the changes in muscle strength before and after intervention were as follows: experimental data: 35.2 N · m before intervention, 42.5 N · m after intervention, with an increase of 7.3 N · m. Simulation data: 35.1 N · m before intervention, 42.2 N · m after intervention, with an increase of 7.1 N · m. The error range is within 0.2 N · m, with an error percentage of approximately 2.7%, which is considered very small in biomechanical simulations. The difference in data between the control group is even smaller, and the difference between experimental and simulated data is almost zero, which is in line with expectations. Through simulation and experimental comparative analysis of muscle strength between the experimental group and the control group at different time points, the simulation results of the experimental group and the control group are consistent with the experimental data, proving the effective improvement of muscle strength in elderly people through comprehensive exercise intervention. The simulation model constructed and designed in this article successfully predicted the impact of intervention on muscle strength in the elderly population, providing reliable simulation support for future related intervention research [46].

The comparison between the simulation results and actual experimental data provides valuable insights into the effectiveness of the intervention as well as the reliability of the simulation model [47]. While the experimental group showed consistent and significant increases in muscle strength over the course of the study, the control group exhibited minimal changes, which were well-reflected in both the experimental and simulation data. The close alignment between the simulation data and experimental results in the experimental group, particularly in the 3- and 6-month post-intervention periods, suggests that the model successfully captures the trend of muscle strength improvement over time, with only a small error margin of around 2.7%. However, the fluctuations in the experimental group's error at different time points could indicate the influence of individual variability or environmental factors, such as differences in adherence to the intervention or measurement inconsistencies [48]. These fluctuations suggest a limitation of the simulation model, where real-world variability might not be fully accounted for, and highlight the need for further refinement in modeling the impact of such interventions on a diverse population. Furthermore, while the model fits well with the control group data, where changes were minimal, the lack of significant variability in the control group's data limits the ability to assess how well the model would handle more complex or dynamic scenarios [49]. Overall, the simulation provides a useful tool for predicting intervention outcomes, but the observed discrepancies suggest that future models should aim to incorporate more individualized factors and improve adaptability to a wider range of participants. This approach will increase the generalizability and precision of the simulation in predicting real-world outcomes.

5. Conclusion

This study theoretically analyzes and experimentally verifies the biomechanical mechanisms through which sports interventions improve the internal abilities of elderly individuals. The results demonstrate that a 12-week exercise program significantly enhances muscle strength, joint flexibility, and balance ability, thereby improving the overall physical function and quality of life of elderly participants. Specifically, the intervention group showed marked improvements in gait performance ($p < 0.05$), muscle strength (measured by electromyography), and joint range of motion, compared to baseline and control groups. Furthermore, the long-term follow-up at 24 months revealed that the positive effects of exercise, particularly in balance and joint flexibility, persisted, although with some gradual decline, suggesting that continued physical activity is necessary to maintain these benefits.

Despite these promising findings, the study has several limitations, including a small sample size and a relatively short intervention period. Future research should aim to expand the sample size and explore the effects of different types of exercise regimens, such as aerobic versus resistance training, on long-term health outcomes in the elderly. Additionally, incorporating more diverse participant demographics and increasing the duration of the intervention could provide further insight into the sustainability of exercise-induced benefits. Longitudinal studies with larger sample sizes are recommended to better understand the enduring impact of exercise interventions on the biomechanics and intrinsic capacity of aging individuals, ultimately contributing to more effective public health strategies for the elderly population.

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Conflict of interest: The authors declare no conflict of interest.

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