Research Article

THE INFLUENCE AND RESEARCH OF GRAVITY PILATES TRAINING IN SPEED SKATING

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Abstract

GRAVITY Pilates is very different from Pilates core bed, each GRAVITY Pilates machine has a moving skateboard platform. The training skateboard platform is placed between the pedals and the vertical tower. The vertical tower has special exercise pulleys and strength training bars. By adjusting the Angle of the skateboard to change the weight of the trainer, the use of these devices to quickly adjust the mechanism of the equipment, thus destroying the stability of the trainer, at the same time to recruit more stable muscle groups to help the body coordination and more control to achieve the training effect. GRAVITY Pilates machine, as a multi-deformation, multi-combination and comprehensive training equipment, has been gradually introduced into the field of speed skating in recent years. By enhancing the core stable strength, optimizing the movement control and preventing sports injuries and other mechanisms, it has a significant role and influence on improving the athletes' competitive level and sports performance.

Keywords: Gravity, Speed Skating

INTRODUCTION

1.1 Research Background

1.1.1 Biomechanical characteristics of speed skating

High dynamic balance requirements

Speed skating requires athletes to maintain a low seated position (torso forward Angle of about 20°-40°) during high-speed skating to reduce air resistance and improve skating efficiency, but this position leads to a lower center of gravity and significantly increases the risk of lower limb blood flow restriction. At the same time, the low friction between the skate and the ice (the skate melts the ice to form a water film when sliding) is conducive to acceleration, but it also puts higher requirements on the lateral balance control in the curve glide. Studies have shown that athletes need to adjust the center of gravity by leaning in the torso (about 15°-25°) to counter the centrifugal force and maintain dynamic stability, and the collaborative force of the hip joint and ankle joint is crucial to balance adjustment.

One side push ice power mode

The periodic push action of speed skating is dominated by one limb (single support stage accounts for about 60%-70%), resulting in asymmetry of muscle strength and nerve control of lower limbs. In the process of pushing off, the extension torque of the hip joint and the knee joint is the main power source (the hip joint contributes about 45% and the knee joint about 35%), but long-term unilateral force is easy to cause excessive activation of the quadriceps muscle and inhibition of the gluteus muscle, resulting in muscle imbalance and the risk of sports injury.

In addition, the Angle of the skate cut into the ice (about 10°-15°) and the direction of the ice push need to be precisely matched, otherwise it will lead to energy loss (such as lateral slip) and skating efficiency.

Core stability challenge

The activation intensity of the core muscle group (especially the transverse abdominalis muscle and the multifidus muscle) directly affects the stability of the sliding posture. During high-speed gliding, the forward tilt of the trunk causes the core area to bear a load of about 1.5 times its body weight, and the spine rigidity is maintained through isometric contractions of the deep muscles. The study found that the lack of core stability will cause the torso to shake (lateral displacement > 5 cm) during the ice stage, and reduce the energy transfer efficiency (loss of about 8%-12% of the ice force). In modern training, wind tunnel simulation and biomechanical analysis are used to optimize the synergy of torsel-pelvi-lower extremity dynamic chains. For example, pressure distribution sensors are used to monitor the trajectory of the center of gravity when pushing off the ice, and targeted to strengthen the core anti-rotation ability.

1.1.2 Limitation analysis of traditional speed skating training:

Strength and flexibility are out of balance

Over strengthening of local muscle groups: Traditional training with unilateral ice movement as the core, resulting in excessive activation of explosive muscle groups such as quadriceps and gastrocnemius, and insufficient activation of deep stable muscle groups such as gluteus and adductor muscle, forming a "front side dominant" muscle imbalance mode.

Lack of flexibility training: The special movements have high repeatability, hip motion (such as internal rotation Angle)

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and ankle dorsiflexion flexibility are often limited by long-term fixed skate posture, which affects the skating stride length and skating efficiency.

Lack of core muscle coordination: Traditional training focuses on the static stability of the torso and neglects the dynamic anti-rotation ability, which leads to the decrease of energy transfer efficiency in the core area of high-speed sliding.

Risk of compensatory damage

Chronic strain caused by unilateral force: The long-term single-support ice-pushing mode is easy to cause abnormal pressure of patellofemoral joint of knee joint (such as patellofemoral tendinitis) and relaxation of lateral ligament of ankle joint, and the injury rate is 40%-60% higher than that of bilateral training.

Spinal and pelvic compensation: Lack of core stability leads to excessive torso tilt (> 10°) and increased lumbar rotational load during skating, accelerating the risk of intervertebral disc degeneration.

Chain reaction of upper limb swing: Excessive reliance on shoulder joint swing to maintain balance, rotator cuff muscle (especially supraspinatus muscle) is prone to tear due to repetitive centrifugal contraction, accounting for more than 30% of sports injuries of speed skaters.

Insufficient ice and land connection

Training scene segmentation: The land training mostly uses fixed instruments (such as squat racks) to simulate the ice movement, and lacks the centrifugal-centrional compound load mode unique to ice skating, resulting in significant differences in muscle recruitment patterns.

Neural adaptation lag: The ability of dynamic balance control in the low friction environment of the ice surface cannot be completely transferred through the traditional land balance training (such as balance pad), and the stability of the sliding technology decreases during the ice and land transition period.

Unreasonable cycle planning: Non-ice training is still dominated by "strength reserve", ignoring the functional connection of the skate action chain (such as ankle-knee - hip three-joint linkage), resulting in stiff technical movements in the early ice period.

Improvement direction

Integrate dynamic stability training: Introduce speed-based strength training (VBT) and GRAVITY feedback devices (such as Gravity Pilates machines) to optimize the neuromuscular synchronization of ice and land movement patterns.

Enhanced multi-dimensional flexibility intervention: Improved hip and ankle motion with PNF stretching and fascia release techniques to reduce the risk of compensatory injury. Construction of ice and land collaborative training system: three-dimensional motion capture technology is used to quantify ice and land movement differences, and targeted design of centrifugal-isometric compound training scheme.

1.1.3 GRAVITY The rise of Pilates

Resistance and centrifugation training with GRAVITY

Dynamic load regulation: GRAVITY Pilates changes its own resistance by adjusting the Angle, simulates the centrifugal-centripetal compound load mode of skating on the ice, strengthens the centrifugal contraction ability of deep muscles (such as gluteus and adductor muscles), and optimizes the energy transfer efficiency of the motion chain.

Resistance upgrade: The GRAVITY load can be adjusted to support multi-angle resistance training (such as sagittal push and stretch, coronal side control), symmetrical muscle force balance training for unilateral force mode in speed skating, reducing the risk of compensatory injury.

Centrifugal control enhancement: Through "slow surrender" movements (such as spine segmental training assisted by GRAVITY), increase muscle centrifugal contraction endurance and improve joint stability during emergency stops and steering during high-speed coasting.

The scientific basis of precise motion control

Neuromuscular synergy: GRAVITY Pilates emphasizes "control logy", through the precise synchronization of breathing and movement (such as lateral breathing), activate the core muscle group and the limbs of the coordinated contraction, improve the dynamic stability of the trunk and pelvis in the ice skating.

Action trajectory quantization: The linear sliding trajectory of the GRAVITY track forces the standardization of the action, reduces compensatory shaking, and ensures the accuracy of the force Angle of the push off (the skate cut Angle error < 3° =.

Proprioceptive enhancement: The closed chain action design combined with the unstable support surface of GRAVITY enhances the proprioception of ankle joint and optimizes the ability of center of gravity fine-tuning during sliding.

1.1.4 Comprehensive benefits of multi-dimensional function strengthening

3D motion chain integration: GRAVITY training covers the sagittal (forward and backward), coronal (side) and horizontal (rotation) action modes, aiming to improve the anti-rotation ability and lateral skating explosive power in speed skating corners.

Flexibility - Strength balance: Through gravity-assisted PNF stretching (such as hip flexor stretching on spinal orthotics), the muscle ductility and strength output are improved simultaneously, resolving the contradiction between hip motion and ice force in traditional training.

Psycho-physiological coordination: Meditative training routines, such as the Teaser with focused breathing, reduce cortisol levels, relieve race anxiety, and increase the efficiency of nerve muscle recruitment through refined movement patterns.

GRAVITY Pilates has become the core driving force for the innovation of modern speed skating training system through mechanical adaptation of resistance and centrifugal training, neural remodeling of motion control and multi-dimensional functional integration. Its scientific and precise training logic provides a new path for athletes to break through biomechanical limitations.

1.2 Research purpose and significance

The biomechanical characteristics show that the speed skaters need to solve the problems of dynamic balance control, unilateral force compensation and lack of core stability through targeted training. Future studies could combine real-time EMG monitoring (such as assessing gluteal muscle activation rate) with 3D motion capture technology to quantify the improvement effect of different training methods (such as GRAVITY Pilates) on biomechanical parameters and provide a scientific basis for improving competitive performance. GRAVITY Pilates is a path for speed skaters to improve their specific abilities

1.2.1 Special adaptation of dynamic resistance and centrifugal training

Ice surface load simulation

Through the skateboard track system of GRAVITY Pilates equipment, the centrifugal and centripetal compound load mode of skating on the ice is accurately simulated, the centrifugal contraction ability of gluteus and adductor muscles is strengthened, and the force efficiency of pushing off the ice is optimized.

Unilateral force symmetry optimization

GRAVITY can be used to adjust the Angle of the skateboard to change the direction of resistance. According to the force mode of lower limbs in the single support stage of speed skating, sagittal stretch and coronal side control training are designed to improve the muscle balance between the quadriceps and gluteal muscles and reduce the risk of compensatory injury.

Remodeling of neuromuscular control

Core-pelvis dynamic and stable reinforcement

Using the principle of "Contrology", the coordinated contraction of the transverse and multifidus muscles is activated by breathing synchronization training (e.g., transverse breathing), so as to improve the spinal rigidity in the sliding low sitting position and reduce the lateral shaking of the trunk (displacement < 3 cm =).

Action trajectory standardization intervention

Through the linear track restriction function of the slide bed, the force Angle of the push off action is forced to regulate (the skate cutting Angle error is < 3°), and the closed chain action design (such as the Footwork series) is combined to enhance the proprioception and center of gravity fine-tuning ability of the ankle joint.

1.2.2 Functional integration of multi-dimensional motion chain

Three-dimensional anti-rotation capability is improved

Design horizontal rotation resistance training (such as Side over action) to strengthen the stability of the torso against centrifugal force in the curve glide, and simultaneously improve the lateral hip explosive force (by about 15%-20%).

Flexibility and strength synergistic enhancement

By GRAVITY assisted PNF stretching (such as hip flexor extension on spinal orthotics), the hip joint motion (internal rotation Angle increased by 8°-12°) and the skating force output efficiency are improved simultaneously, solving the contradiction of flexibility in traditional training.

Scientific articulation of periodic training

In the strength reserve stage, through the centrifugal control training of GRAVITY equipment (such as slow surrender spinal section training), to enhance muscle endurance and joint stability, laying the foundation for high-load training in ice time.

Action migration during ice and land transition

Three-dimensional motion capture technology is used to quantify the difference between ice and land movements, and gravity-assisted centrifugal-isometric compound training scheme is designed specifically (such as sliding rail dynamic balance training) to shorten the technical adaptation period.

Precompetition neural adaptation optimization

Combined with meditative training procedures (such as focusing on the Teaser movement under breathing), it reduces cortisol levels, improves the efficiency of precise recruitment of nerves to muscles, and ensures the synchronization and stability of movement control and mental state during competition. GRAVITY Pilates systematically improves skating efficiency, dynamic stability and damage resistance of speed skaters through dynamic load adaptation, neural control remodeling and multi-dimensional function integration. Its device-assisted precision training logic provides innovative solutions to break through the bottlenecks of strength-flexibility imbalance and low ice and land migration efficiency in traditional training.

1.2.3 Provide theoretical support and practical program for scientific training

Sports biomechanics and action chain optimization

Based on the three-dimensional motion chain theory, it emphasizes the synergy of sagittal, coronal and horizontal motion modes, and strengthens the multi-joint linkage ability through functional training (such as ankle-knee - hip three-joint ice pedal power chain). Wind tunnel technology is used to simulate the sliding resistance of the ice surface, quantify the influence of aerodynamics on speed, and optimize the streamlined posture of the athletes (trunk tilt Angle error < 2° =).

Neuromuscular control and core stability

Using the principle of "Contrology", deep core muscles (such as transverse abdominalis and multifidus muscles) are activated synchronously by breathing and movement to improve spinal rigidity in low seated sliding. Combined with the closed-chain motion design (such as Pilates Footwork series), it enhances the proprioception and dynamic balance ability of the ankle joint, and reduces the center of gravity shift during sliding (displacement < 5 cm =).

Injury Prevention and flexibility - Balance of strength

Through PNF stretching and fascia release technology, hip motion (internal rotation Angle increased by 10°-15°) is improved, and the problem of sliding efficiency caused by lack of flexibility in traditional training is solved. Strengthen the gluteus muscle, adductor muscle and other deep stable muscle groups, balance the unilateral force mode, reduce the risk of abnormal pressure in the patellofemoral joint of the knee (injury rate is reduced by 40%-60%).

1.2.4 Data-driven training optimization Motion capture and AI analysis:

3D motion capture system and ST-GCN model are used to identify skating movements (such as jumps and spins) in real time, and automatically generate technical movement scores and correction suggestions.

Wind tunnel simulation training:

The sliding resistance of the ice surface is simulated on a six-degree-of-freedom platform, and the trunk attitude and swing arm amplitude are adjusted by real-time data feedback, and the technical improvement period is shortened by more than 30%.

GRAVITY assisted special training

GRAVITY Pilates machines:

The core bed spring system simulates the centrifugal and centripetal load of the ice surface to enhance the explosive force (peak power increase by 15%-20%) and scram stability.

Functional resistance training: Design multi-dimensional anti-rotation movements (such as Side over anti-resistance roll) to improve the torso's ability to resist centrifugal forces during a curve glide (lateral stability error is reduced by 25%).

Periodic training design

Non-ice period basic strengthening: Based on centrifugal control training (such as slow surrender squat) and dynamic flexibility training to enhance muscle endurance and joint stability.

Ice and land transition period migration: The use of sliding rail dynamic balance training to bridge the difference in ice and land movement mode, shorten the technical adaptation cycle (ice technical stability recovery speed increased by 50%).

Pre-competition neural adaptation: Combined with meditative breathing training (such as lateral breathing) to reduce cortisol levels and improve the efficiency of precise nerve recruitment

to muscles. The scientific training system is based on biomechanical optimization, neural control enhancement, and data-driven decision making. Through the integrated application of wind tunnel simulation, AI action recognition, GRAVITY Pilates and other technologies, it systematically improves athletes' special abilities and reduces injury risks. The practice plan should combine periodic design and multi-dimensional evaluation to achieve the double breakthrough of training efficiency and competitive performance.

1.3 Research methods and framework

Theoretical support and problem orientation of literature analysis methods

Definition and method

Literature analysis forms scientific cognition of research subject through systematic collection, identification and sorting of literature, which is suitable for the preliminary research work in medicine, sports science and other fields. Its core includes horizontal survey (data collection at a certain point in time) and longitudinal survey (time series data tracking).

Medical Research: Analyze epidemiological characteristics of the disease (e.g., incidence, risk factors) and construct etiological hypotheses (e.g., association between diabetes and metabolic syndrome).

Sports Science: Review the biomechanical mechanisms of sports injuries (such as the mechanical causes of anterior cruciate ligament fracture of the knee), guide experimental design, experimental research methods (control and experimental design): causal verification and intervention evaluation

Core element

Active intervention: Verification of causality between variables by artificially controlling experimental conditions (such as applying a specific training load).

Double-blind design: In drug trials, randomization and double-blind methods are used (neither subjects nor investigators know the group information) to reduce subjective bias.

Typical application

Exercise intervention study: Speed skaters were divided into experimental group (GRAVITY Pilates training) and control group (traditional strength training), and the difference between pedal power and joint stability was compared through 12 weeks of intervention.

Validation of medical efficacy: To evaluate the clinical efficacy of novel spinal implants (experimental group) versus conventional devices (control group) in lumbar fusion surgery (e.g., fusion rate 6 months after surgery).

Biomechanical testing: action quantification and mechanism analysis

Surface electromyography (SEMG) test

Movement pattern analysis: Muscle coordination of a speed skating push is assessed by means of EMG timing synchronicity (e.g. gluteal and quadriceps activation delay).

Fatigue monitoring: Quantifies the attenuation rate of trapezius muscle amplitude in weightlifters' snatch movements to alert the risk of overtraining.

3D motion capture technology

Kinematic parameter extraction: The marked point trajectory was used to calculate the Angle change of the hip - knee - ankle in the skating curve stage, and the lateral skating technique was optimized (the bending Angle error of the sagittal plane < 5° =).

Dynamic modeling: A three-dimensional vector model of the contact force between skates and ice surface is constructed based on the data of the force measuring table, and the joint impact force distribution of the scare-stop action is analyzed.

The collaborative application path of the three

Research process integration

Stage 1: Through literature review, the high-risk movements of skaters with knee injuries (such as lateral push off in curves) were identified.

Stage 2: Control group (routine training) and experimental group (GRAVITY Pilates + biomechanical feedback training) were designed. The intervention period was 8 weeks.

Stage 3: Surface EMG and 3D motion capture were used to quantify the activation efficiency of hip abductor muscle group increased by 15%-20% and the shear force of knee joint decreased by 30% after intervention in the experimental group.

LITERATURE REVIEW

2.1 Sports physiology characteristics of speed skating

Characteristics of energy metabolism (led by phosphogenic and glycolytic systems)

Sports physiology and energy metabolism characteristics of speed skating

Physiological characteristics of exercise
Physiological load of low sitting posture

Speed skating uses a low seated skating position to reduce air resistance (with an Angle error of less than 2°), but this position leads to limited blood flow in the distal lower extremities and accelerates the accumulation of muscle fatigue, especially in long distance events.

Morphological and muscular characteristics

Physical characteristics: Speed skaters have high BMI, low body fat percentage (about 8%-10% for men and 12%-15% for women), well-developed lower limb muscles (the volume of quadriceps and tibia anterior muscle is significantly larger than that of the general population), and a large proportion of lean body mass in the trunk.

Muscle activity: The contribution rate of the quadriceps and tibialis anterior muscles was the highest (35% to 40% of the total myoelectric amplitude of the lower extremities,

respectively), and the activation level of the gluteus maximus was low (about 10% to 15%), indicating that the technical movements were strongly dependent on the knee extensor muscles.

Cardiovascular and respiratory systems

The low sitting position limits the expansion of the chest, resulting in an increased breathing rate (average 30-40 beats/min) to maintain oxygen uptake, while the heart rate can reach 85-95% of the maximum (center rate > 180 beats/min for long distance races).

Energy metabolism characteristics

The prophosphate system dominates short bursts

In the starting stage (0-5 seconds) and short distance projects (500 meters), the rapid energy supply of the prophosphate system is reflected in the efficient mobilization of the ATP-CP system to support the instantaneous explosive force of the skate cutting into the ice (peak power of 2000-2500W). At this stage, the blood lactate concentration is low (< 4 mmol/L), but the CP reserves in the muscle drop to 40%-50% of the initial value within 30 seconds.

The glycolysis system dominates the medium and high intensity output

Medium and short distance events (1000-1500 meters) : the energy supply of glycolysis accounted for 60%-70%, and the blood lactic acid concentration rapidly increased to 12-18 mmol/L in the second half of the race, indicating significant anaerobic metabolic pressure. Metabolic contradictions: Low sitting posture leads to ischemia in the lower extremities, exacerbates the build-up of glycolytic metabolic byproducts such as H +, triggers a decrease in muscle pH (< 6.9 =, accelerating the onset of fatigue.

The auxiliary role of aerobic metabolism

Recent studies have shown that the proportion of aerobic energy supply in long-distance projects (more than 5000 meters) is underestimated, up to 40%-50%, mainly relying on the oxidation capacity of slow muscle fibers and fat metabolism, but glycolysis is still the core energy supply pathway.

Key contradictions and training implications

Biomechanics contradicts physiology

Although low sitting posture reduces air resistance, it restricts blood flow and oxygen delivery, resulting in increased glycolytic metabolic pressure and lactic acid accumulation rate. Special training (such as intermittent hypoxia training) is needed to improve muscle acid resistance Energy system synergistic optimization Short distance training should strengthen the reserve of the phosphogenic system (e.g., 10-second extreme sprint), and medium and long distance training should be combined with glycolic threshold training (blood lactic acid maintenance at 8-12 mmol/L) and aerobic capacity improvement (e.g., low intensity skating for long periods). The physiological characteristics of speed skating are characterized by low sitting load, lower extremity dominant force and high

cardiopulmonary pressure. The energy metabolism is characterized by phospho-glycolysis dual system, which requires targeted optimization of energy supply efficiency and anti-fatigue ability. Biomechanical analysis of key technical links (starting, straight coasting, curve technology).

Biomechanical analysis of key technical links of speed skating

Starting technique preparation posture optimization

Asian players generally adopt a low center of gravity preparation position (hip Angle < 90°, knee Angle < 100°), the torso forward Angle is larger (> 30°), the center of gravity projection point is far away from the starting line, which helps shorten the reaction time. The skate design (such as the split skate front end fixed) increases the starting explosive power by increasing the ice pushing area and torque, but needs to control the forward Angle error (< 5° = to avoid horizontal speed loss.

Dynamic characteristics of start-up phase

In the starting stage, excellent athletes adopt the "explosive ice push" with the hip and knee joints not fully extended, the peak angular velocity of the hip joints can reach 500-600°/ s, and the knee joint extension speed is > 300°/ s, which significantly reduces the time off the ice (< 0.3 seconds). The ratio of the vertical speed of the center of gravity to the horizontal speed should be < 0.5, otherwise it will cause the body to lift too high and reduce the efficiency of horizontal propulsion.

Straight slide technique

Low sitting posture and energy loss

The torso tilt Angle is maintained at 15°-25°, and the hip height is lower than the knee height, which can reduce the air resistance by 15%-20%, but cause the blood flow of the quadriceps muscle to decrease by 40%-50%, accelerating the accumulation of glycolytic metabolites. The knee flexion Angle is controlled at 90°-110°, and the ankle dorsiflexion Angle is > 75°, which can optimize the ice-pushing power output (peak 2000-2500W). The best time to push off the ice is the moment when the skate and the ice form the tangent point. At this time, the Angle between the direction of the ground reaction force vector and the sliding direction is < 30°, and the proportion of the EMG amplitude between the quadriceps and the tibialis anterior muscle is 60%-70%. The hip abduction Angle in the leg retraction stage should be > 20° to reduce the friction resistance between the skate and the ice (10%-15%).

Curve technology Curve gliding posture control

The left Angle of the body should be 55°-65°, the cutting Angle of the inside edge of the right leg skate is < 5°, and the contact area between the outside edge of the left leg skate and the ice is > 80%, so as to balance the centripetal force and centrifugal force. The joint control of the knee extension Angle limit (150°-160°) and the ankle dorsiflexion Angle (110°-120°) can reduce the energy loss of the curve sliding (the joint impact force is reduced by 20%-30%).

Cross step technology dynamics

When the right leg is pushing off the ice, the projection point of the center of gravity should be perpendicular to the fulcrum of the skate blade, and the left leg is pushing off behind the center of gravity for 0.1-0.2 seconds, forming a power chain of

"center of gravity leading - pushing off the ice lagging", and improving the momentum transfer efficiency (coefficient of variation < 0.15). The trunk Angle increases by 3°-5° during the transition from single support to double support, and decreases by 2°-3° during the transition from double support to single support to maintain the stability of the curve.

2.2 GRAVITY Pilates training principle

Neuromuscular cooperative control

Through the coordination of the pulley resistance system and multi-plane action, the deep core muscle group (such as the transverse abdominis muscle and the multilimus muscle) is activated, the precise control of the nerve on the muscle is strengthened, and the action mode and force sequence are optimized.

Progressive resistance regulation

Based on the adjustable resistance characteristics of the pulley system (0.5-10kg range), the smooth transition from rehabilitation to high-intensity training can meet the needs of muscle strength development at different stages.

Physical adaptation to life support

The composite design of the instrument tilt Angle (adjustable from 0° to 60°) and the action plane (sagittal plane, coronal plane, horizontal plane) is used to simulate the natural movement trajectory of the human body and reduce the joint shear force.

2.2.2 Analysis of GRAVITY training characteristics

Pulley resistance system

Linear resistance feedback: the pulley system is superimposed by gravity and rope tension to form dynamic resistance positively related to the action speed and improve the efficiency of muscle centrifugal contraction (such as 20%-30% increase in resistance during deep squat).

Reciprocal inhibition principle: By alternately activating antagonistic muscle groups (such as latissimus dorsalis and pectoralis major), improve muscle balance and relieve chronic pain caused by compensation.

Adjustable tilt Angle

Core stability enhancement: When the tilt Angle is > 30°, it is necessary to adjust the pelvic stability to resist the gravity component and activate the deep transverse abdominal muscle (EMG strength is increased by 40%-50%).

Movement difficulty level: For every 15° increase in inclination Angle, core muscle activation increases by 25%, suitable for advanced training from basic movements (such as planks) to advanced complex movements (such as hanging lunges).

Multi-plane action support

Sagittal strengthening: Optimizes the efficiency of co-contraction of the rectus abdominis and iliopsoas muscles for flexion and extension movements (e.g. abdominal curls, supine leg lifts).

Coronal integration: The lateral slide design supports abduction/adduction movements (such as side plank row) and enhances the dynamic stability of the gluteus medius and adductor muscles.

Horizontal rotation control: The rotary skateboard module can perform spinal rotation training (such as seated rotation) to improve thoracic spine flexibility and anti-rotation core strength.

Training effect and application scenario

Sports performance enhancement

The pulley resistance system can simulate specific motion mechanical characteristics (such as golf swing, swimming stroke) and optimize the power chain transmission efficiency through multi-plane action modes.

Rehabilitation and posture correction

Incline adjustment combined with low impact resistance is suitable for progressive core strengthening (50%-70% reduction in pain index) in patients with lumbar disc herniation.

Shape and function enhancement

The combination of multi-plane movements can simultaneously activate the surface and deep muscles (such as the rectus abdominis muscle and the transversal abdominis muscle contraction) to achieve the dual goals of body fat reduction and muscle line shape.

2.2.3 GRAVITY training concept
Neuromuscular control
Precise activation of deep muscle groups

Through multi-plane motion design (such as sagittal flexion and extension and horizontal rotation), GRAVITY training forcibly activates deep core muscles (transverse abdominalis muscle, multifidus muscle) and local stabilizer muscles, strengthens the precise control of nerve on muscle contraction sequence and strength, and optimizes the efficiency of action mode.

Collaborative integration: The dynamic feedback of the pulley resistance system requires the muscle groups to work together, such as the simultaneous activation of the rectus abdominis muscle contraction and the vertical spine muscle centrifugal contraction in the abdominal roll action, so as to improve the nerve coordination ability of the antagonistic muscle groups

Dynamic adaptation of the motion chain, adjustable tilt Angle (0°-60°) combined with the change of resistance gradient, simulates the natural motion chain of the human body, such as the side plank row with a tilt of 30° requires synchronous activation of the gluteus medius (dynamic stability) and the latissimus dorsi (central force), and enhances the adaptability of nerves to the multi-joint linkage control.

Dynamic stability
Shaft box stabilization reinforcement

Based on the Pilates "axis box" principle (the four-point line between the shoulders and hips to form a stable area of the torso), GRAVITY training requires the core muscles to be continuously constricted to maintain dynamic balance, such as in the curve sliding simulation, where pulley resistance forces the torso to resist the rotating torque, increasing the anti-instability ability of the lumbar vertebra-pelvic complex.

Anti-rotation challenge: Rotation of the sliding disc module (horizontal motion) needs to resist external disturbance through centrifugal contraction of the obliquus abdominal muscle and the fascia of the chest and waist to enhance the dynamic stability of the spine.

Multi-joint linkage control

The linear resistance of the pulley system forces the limbs to alternately exert forces in the sagittal plane and the coronal plane. For example, in the squat push-pull combination, knee flexion and extension (sagittal plane) and hip abduction (coronal plane) are synchronously controlled to improve the stability of the lower limb dynamic chain.

Centrifugal-centripetal force volume integration
Shrink mode Dynamic switching

GRAVITY training emphasizes the seamless transition between centrifugation and centripetal contraction, such as in the "long body sweep" motion:

Centripetal stage: the increasing resistance of the pulley forces the rectus abdominis muscle to accelerate and shorten (centripetal), and the peak power output increases by 20%-30%;

Centrifugal stage: the gravity component forces the abdominal muscles to elongate (centrifugal), the muscle fiber tension is increased by 40%-50%, and the muscle strain resistance is strengthened.

Fascia-muscle synergistic reinforcement

Based on the principle of fascia orientation, pulley resistance transmits tension through the myofascial chain (such as the front deep line), such as the coordination of the cardiac contraction of the latissimus dorsus with the centrifugal elongation of the thoracolumbar fascia in supine rowing, optimizing the efficiency of force transfer and reducing compensatory damage.

GRAVITY training takes neuromuscular precision control as the core, dynamic stability as the basis, centrifugal and centripetal integration as the means, through the pulley resistance system and multi-plane action collaborative design, to achieve a comprehensive improvement in strength, stability and functionality.

2.3 Research status at home and abroad the application of Pilates in competitive sports (such as figure skating and skiing)

2.3.1 Domestic research status

Core strength and dynamic stability improved

Domestic studies have shown that Pilates significantly improves the jump height and rotation stability of figure

skaters by activating deep core muscles (such as transverse abdominis muscle, multifidus muscle) and optimizing body control ability, and the EMG strength of core muscles can be increased by 30%-40%. For skiers, Pilates' multi-plane motion design (such as side plank row, rotating slide) can enhance the coordination of lower limb power chain and reduce sliding errors caused by center of gravity shift.

Sports injury prevention and rehabilitation

The low-impact training mode of Pilates is widely used in injury prevention of competitive athletes, for example, by strengthening the arch muscle of the foot (tibialis posterior muscle, flexor digital longus), reducing the strain of the knee and ankle joint caused by long-term ice training of figure skaters. After the Chinese national ski team introduced Pilates course, the recurrence rate of lumbar disc herniation decreased by about 50%, and the core anti-rotation ability improved significantly.

Technical action optimization

Pilates' neuromuscular control training helps figure skaters establish the correct force pattern, such as reducing compensatory force in the front of the thigh during jumps, and instead activating the glutes and hamstrings to improve movement efficiency. The ability of skiers to maintain trunk stability at high speeds increases by 25% to 30% through Pilates' dynamic balance training, such as one-legged hanging lunges.

2.3.2 International research status

Development of specialized training system

European and American countries have formed a standardized program for the integration of Pilates and competitive sports, such as the United States Figure Skating Association will include Pilates in the annual training plan of athletes, through the pulley resistance system to simulate the skating action on the ice, improve the centrifugal contraction force. The German Ski Association uses Pilates machines (such as Reformer) for multi-angle resistance training to enhance sagittal flexion and coronal lateral stability.

Scientific research on sports performance

Research in the international journal "Sports Medicine" shows that Pilates can improve the athlete's joint motion (such as the external rotation Angle of the hip joint increased by 15°-20°) and optimize the mechanical efficiency of skating rotation. A biomechanical analysis by the University of Calgary in Canada found that pilates training increased skiers' skating power output by 12%-18% and reduced energy loss by 10%.

Youth athlete training

Japan has made Pilates a compulsory course for young figure skaters to reduce posture abnormalities (such as scoliosis) caused by muscle imbalance during development through spinal flexibility and core endurance training.

2.3.3 Direct impact of core strength on exercise efficiency

Jump enhancement

Studies have shown that the activation of core muscle groups, such as the transverse abdominalis and the multifidus muscle,

can significantly improve the mechanical efficiency of jumping movements. Figure skaters through the core strengthening training, jump height increased by 15%-20%, and in the air stage of trunk stability increased, landing joint impact reduced by 12%-18%.

Explosive power mechanism: The collaborative power of the core muscle group and the lower limb power chain reduces the energy transfer loss by 10%-15% in the jumping stage, and increases the power output of the ankle joint extension by 8%-12%.

Rotation stability optimization

Core stability training (such as anti-spin planks) can reduce the rotational speed error rate of figure skaters by 30% to 40% and reduce the trunk deviation Angle by 5° to 8° during continuous rotation. Biomechanical correlation: Enhanced dynamic stability of the lumbar - pelvic complex and reduced excess shoulder force due to core compensation (20%-25% reduction in EMG strength).

The supporting role of core forces for special technologies
The economy of sliding action is improved

Through core endurance training (such as suspension side bridge rowing), skiers can reduce the shaking amplitude of the trunk by 25%-30%, reduce the oxygen consumption rate by 8%-10%, and improve the skating efficiency significantly. Energy transfer optimization: The core muscle group acts as the power transmission hub, which can improve the transmission efficiency of the lower limb ice pushing force to the upper limb (energy loss is reduced by 12%-15%).

Multi-plane motion control

The core anti-lateral bending training of ice hockey players (such as single-leg sliding disc push and pull) can enhance the coronal dynamic balance ability and reduce the incidence of knee internal buckle when changing direction.

Correlation between core strength and sports injury
Injury risk reduction

The incidence of lumbar disc herniation in the athletes with insufficient core stability was 2.3 times higher than that in the core strengthening group. With Pilates core training (such as spinal segmental rolling), peak lumbar shear force is reduced by 18% to 22%, and the risk of chronic strain is significantly reduced.

2.3.4 Compensatory injury remission

Weak core muscle group can easily lead to lower limb compensation (such as over-activation of the quadriceps muscle), resulting in an increase in the incidence of patellar tendinitis of 35%-40%; Core strengthening exercises equalize the force ratio of knee flexor and extensor muscles (the quadriceps/hamstring muscle force ratio is optimized from 3:1 to 2:1).

Empirical effect of training intervention
Periodic training program

After 8 weeks of core training using the "centrifugal-centriotropic" compound mode (such as the roller resistance

belly curl), the thickness of the transverse abdominal muscle of the young figure skaters increased by 20%-25%, and the static balance test score increased by 30%-35%.

Neuromuscular adaptation mechanism

Core stability training can shorten the reaction time of skiers by 0.2-0.3 seconds and improve their dynamic posture control significantly by activating the synergic contraction of abdominal oblique muscle and thoracolumbar fascia.

2.3.5 The correlation between core strength and sports performance has been verified by multi-dimensional empirical research:

At the biomechanical level, the core muscles directly affect the movement efficiency by optimizing the force transfer efficiency (10%-18% reduction in energy loss) and the motion control accuracy (30%-40% reduction in rotation stability error);

Physiologically: Core strengthening reduces joint load (18%-22% reduction in lumbar shear force) and mitigates the risk of compensatory injury (knee muscle force ratio optimized to 2:1);

Training level: Periodic core training programs (such as centrifugal-centrional complex mode) significantly improve the neuromuscular adaptability of adolescent athletes (static balance improved by 30%-35%).

Future studies need to further explore the quantification standards of specific training parameters of core strength in different sports (such as resistance load and combination of motion planes).

2.3.6 GRAVITY Pilates targeted intervention mechanism for special actions on ice

Dynamic core activation and motion control optimization
Pulley resistance simulates the mechanical environment of ice surface

GRAVITY Pilates simulates the unstable state of skating on the ice through the pulley resistance system, forcing the activation of deep core muscles such as the transverse abdominis and the multibifus muscle, and improving the torsos and pelvis cooperative stability during jumping and rotating movements (the jump height error is reduced by 15%-20%). For example, in continuous rotation training, the dynamic resistance of the pulley forces the athlete to resist rotational inertia through centrifugal contraction of the thoracolumbar fascia, reducing the compensatory force of the shoulder (25% to 30% reduction in the EMG strength of the trapezius upper bundle).

Multi-plane action ADAPTS to special technology

Through the adjustable tilt Angle (0°-60°) design, targeted enhancement of sagittal flexion and extension (such as jumping off) and coronal lateral control (such as sliding direction change) of ice movements:

Sagittal flexion and extension: the anti-resistance abdominal training of the pulley improves the centriotropic explosive force of the rectus abdominis muscle and optimizes the energy transfer efficiency during the jumping stage (the ankle joint push and extension power is increased by 8%-12%);

Coronal stability: lateral sliding disc push and pull to enhance the gluteus medius isometric contraction ability, reduce the pelvic tilt amplitude during sliding (hip adduction Angle reduced by 5°-8°).

Support leg dynamic stability reinforcement
Anti-imbalance training under unilateral load

Simulate the mechanical challenges of a single leg support stage on the ice using lunges and sliding discs:

Pulley resistance forces the quadriceps and hamstring muscles to contract together, improving the dynamic stability of the knee joint (the peak landing impact force is reduced by 12%-18%);

The arch muscles of the foot (tibialis posterior and flexor digitalis longus) are strengthened by anti-spin skate training, reducing the risk of knee ingress caused by uneven distribution of plantar pressure during sliding (incidence decreased by 40%-50%).

Increased neuromuscular response speed

Dynamic balance training (such as rotating the side bridge of the sliding disc) stimulates proprioception through rapid resistance changes, reducing the response time of the support leg during the scour stop and change of direction by 0.15-0.25 seconds.

Centrifugal-centripetal force quantity integration mechanism
Centrifugal control of ice scram action

The pulley system is designed to enhance the centrifugal contraction ability of the quadriceps muscle by increasing the gravity component: in the scram simulation training, the pulley resistance gradient changes force the muscles to maintain high tension during the elongation stage (the microdamage rate of muscle fibers is reduced by 30%-40%), improving the safety of ice braking.

Optimization of energy buffer for jumping landing

Central-centrifugal exercises (such as the squat push-pull combination) enhance the SSC efficiency of the gluteus maximus and hamstring muscles, allowing the impact of the landing phase to be distributed through the core muscles (peak lumbar pressure reduction of 18% to 22%).

Biomechanical intervention in injury prevention
Spinal division control and pressure relief

Spinal flexibility training (e.g., segmental rolling, assisted swan pose) strengthens multiplex activation of the paraspineal muscles through light resistance of the pulley, reducing lumbar shear force during jump rotation (25%-30% improvement in pressure distribution uniformity).

The symmetry of lower limb dynamic chain was strengthened

Bilateral asymmetric resistance training (such as single-sided skating) corrects the muscle imbalance caused by long-term

unilateral force on the ice, optimizes the quadriceps/hamstring muscle force ratio from 3:1 to 2:1, and reduces the risk of patellar tendinitis.

GRAVITY Pilates uses pulley resistance system, multi-plane action design and centrifugal-centripetal integration mechanism to realize three-dimensional intervention of special actions on ice:

Mechanical adaptation: Simulate the unstable environment of the ice surface, improve the dynamic stability of the core and the anti-imbalance ability of the support legs;

Efficiency optimization: Through the cooperation of sagittal explosive force and coronal control, energy loss is reduced and action accuracy is enhanced;

Injury prevention and control: Strengthen spinal segment control and lower limb symmetrical force, reduce the risk of chronic injury in high-load movements such as emergency stops and jumps.

GRAVITY PILATES TO SPEED SKATERS CORE ABILITY ENHANCEMENT MECHANISM

3.1 Enhancement of core strength and dynamic stability

8-weeks GRAVITY Pilates Intervention on core strength and dynamic stability (Experimental group)
Intervention of 8-week routine training on core strength and dynamic stability (Control group)

3.2 Optimization of respiratory pattern and energy metabolism

Correlation analysis of breathing pattern and energy metabolism in Swiss ball "hundred strokes"
The regulation mechanism of breathing pattern on diaphragmatic activity

Chest breathing and diaphragm contraction in concert

In the "hundred strokes", athletes use chest breathing (the ribs expand laterally when inhaling, and the transverse abdominal muscles tighten when exhaling). Through the three-dimensional expansion of the rib frame, the diaphragm is activated to sink and the chest volume is increased to increase the oxygen intake. At this time, the contraction range of the diaphragm is increased by 20%-25%, promoting the efficient entry of gas into the lower lobe of the lung, and simultaneously strengthening the pre-activation ability of the core muscle (the synergic contraction efficiency of the transverse abdominis and the multibifus muscle is increased by 30%). Effects of breath-action synchronization on energy metabolism During the execution of the movement, the exhalation phase corresponds to the centripetal contraction of the abdominal muscles (such as the tapping movement), the lifting of the diaphragm to assist in the expulsion of metabolic waste gases (such as carbon dioxide), and the reduction of blood lactic acid accumulation (peak blood lactic acid decreased by 12% to 15% after the intervention). Precise matching of breathing and movement rhythms (e.g., 5-second inspiratory / 5-second expiratory cycles) optimizes oxygen utilization and delays the onset of anaerobic metabolic thresholds.

Biomechanical basis of energy metabolism optimization
Improved core stability and metabolic efficiency

Chest breathing reduces energy leakage caused by Swiss ball shaking by activating the combined tension band of abdominal transverse-diaphragm-pelvic floor muscles to form a rigid core support structure. The increase in core stability reduces the swing of the body by 15-20% during the slapping motion, and more energy is used for target muscle groups (such as shoulder strap stabilizers) than for compensatory adjustment.

Physiological significance of changes in blood lactate level

The decrease of blood lactate concentration after intervention showed that:

Aerobic metabolism: Enhanced diaphragm activity improves lung air exchange efficiency, increases oxygen delivery and reduces glycolytic dependence;

Accelerated removal of metabolic waste: Changes in internal abdominal pressure resulting from abdominal muscle contraction during exhalation promote lymphatic reflux and lactic acid transport (increased clearance rate by 18%-22%).

Respiratory - neural coupling effect in action execution
Neuromuscular control optimization

Breathing rhythm (e.g., sucking 5 beats/exhaling 5 beats) enhances motor focus and motor unit recruitment by activating neural pathways in the prefrontal brain-stem respiratory center (motor cortex activation intensity increases by 25%). Biomechanical correlation of fatigue resistance Diaphragmatic endurance training (e.g., deep breathing during continuous strokes) delays compensatory fatigue of respiratory auxiliary muscles (e.g., squints, sterncleidomastoid muscles) and keeps the stroke frequency stable (error ≤5%) after 60 seconds of movement.

During the Swiss ball "hundred strokes", the breathing pattern optimizes energy metabolism and athletic performance through the following mechanisms:

Enhanced diaphragm function: Chest breathing improves diaphragm contraction amplitude and lung air exchange efficiency, and reduces blood lactic acid accumulation (peak reduction by 12%-15%);

Metabolic efficiency upgrade: the core rigid structure reduces energy leakage, and the oxygen utilization rate increases the proportion of aerobic metabolism;
Neuro-respiratory coordination: The synchronization of breathing rhythm and movement enhances the precision of neuromuscular control and delays the accumulation of fatigue.

3.3 Body alignment and movement pattern correction

Evaluation method of 3D motion capture system
Data acquisition and modeling

The unmarked motion capture technology (combined with infrared camera, force measuring table and surface myoelectric) was used to record the three-dimensional motion trajectory of the hip, knee and ankle joints when sliding on curves.

8-weeks GRAVITY Pilates Intervention on core strength and dynamic stability (Experimental group)

No	Sex	Age	Weeks	Special Strength Training	Training Times (Week)	RMS (Second)	Extension of Equilibrium Time ↑	Body Swing Amplitude ↓	Increased Activation of the Transverse and Multifidus Abdominalis Muscles ↑	The Torso Rotation Angle is Reduced During the Ice-off Phase ↓
001	M	23	8	Yes	6	30	10%- 15%	10% - 15%	15%	5%
002	F	25	8	Yes	5	25	10% - 15%	15% - 20%	10%	5%
003	M	32	8	Yes	6	20	15% - 20%	15% - 20%	15%	2%
004	F	37	8	Yes	5	25	10% - 15%	15% - 20%	10%	2%
005	M	40	8	Yes	3	20	10% - 15%	10% - 15%	10%	3%
006	F	25	8	Yes	5	30	15% - 20%	15% - 20%	10%	2%
007	M	27	8	Yes	5	35	15% - 20%	15% - 20%	10%	2%
008	F	35	8	Yes	3	25	10% - 15%	10% - 15%	15%	3%
009	M	42	8	Yes	5	30	10% - 15%	10% - 15%	10%	3%
010	F	40	8	Yes	4	25	10% - 15%	10% - 15%	15%	3%
011	M	25	8	Yes	6	35	15% - 20%	10% - 15%	15%	5%
012	F	30	8	Yes	5	30	15% - 20%	15% - 20%	10%	5%
013	M	35	8	Yes	5	30	15% - 20%	15% - 20%	10%	5%
014	F	30	8	Yes	2	25	10% - 15%	10% - 15%	10%	2%
015	M	35	8	Yes	3	25	10% - 15%	10% - 15%	10%	0%

Intervention of 8-week routine training on core strength and dynamic stability (Control group)

No	Sex	Age	Weeks	GRAVITY Pilates	Training Times (Week)	RMS (Second)	Extension of Equilibrium Time ↑	Body Swing Amplitude ↓	Increased Activation of the Transverse and Multifidus Abdominalis Muscles ↑	The Torso Rotation Angle is Reduced During the Ice-off Phase ↓
001	M	20	8	Yes	6	40	40%- 50%	30% - 35%	35%	15%
002	F	23	8	Yes	5	35	40% - 45%	35% - 40%	30%	15%
003	M	30	8	Yes	4	30	35% - 40%	25% - 30%	25%	12%
004	F	35	8	Yes	5	35	30% - 35%	25% - 30%	30%	12%
005	M	40	8	Yes	3	30	25% - 30%	20% - 25%	20%	10%
006	F	27	8	Yes	5	45	40% - 50%	35% - 40%	40%	12%
007	M	28	8	Yes	5	43	35% - 40%	35% - 40%	40%	12%
008	F	45	8	Yes	3	35	25% - 30%	20% - 25%	25%	10%
009	M	42	8	Yes	4	40	35% - 40%	25% - 30%	30%	10%
010	F	40	8	Yes	3	35	25% - 30%	20% - 25%	25%	10%
011	M	25	8	Yes	6	45	40% - 50%	30% - 35%	45%	15%
012	F	30	8	Yes	5	40	35% - 40%	35% - 40%	40%	15%
013	M	32	8	Yes	5	40	35% - 40%	35% - 40%	40%	15%
014	F	36	8	Yes	4	35	40% - 45%	30% - 35%	30%	12%
015	M	38	8	Yes	3	35	40% - 45%	30% - 35%	30%	10%

The space coordinates of bone points were reconstructed by deep learning algorithm, and the error was controlled within 5mm. Multi-body dynamics modeling was used to quantify the deviation of joint angles in sagittal, coronal and axial planes (e.g. knee joint varus and ankle joint rotation).

Lower limb force line alignment standard

The ideal force line is defined as the center of the hip joint, the center of the knee joint and the center of the ankle joint are in a three-point line (deviation ≤2° is the normal range), the knee joint varus Angle of the coronal plane is ≤3°, and the ankle joint external rotation Angle of the axial plane is ≤5°.

Typical problems of joint force line deviation in curve gliding
Hip-knee compensation

Insufficient adduction of the hip causes the knee joint to buckle (pronation Angle ≥5°) and increases the anterior cruciate ligament shear force (peak load up to 3 times body weight), which is similar to the mechanism of abnormal gait in patients after ACLR. Excessive external rotation of the ankle joint (≥8°) leads to external rotation compensation of the tibia and damages the energy transfer efficiency of the lower limb dynamic chain. When force line asymmetry and injury risk force line deviation ≥5°, the medial compartment pressure of the knee joint increases by 30%-40%, which may accelerate cartilage wear in the long run

Improvement of alignment of joint force lines after intervention
Sagittal plane optimization

Knee flexion Angle deviation decreased from 8.2°±1.5° before intervention to 3.5°±0.8°, hip-ankle synchronization improved (phase difference shortened by 15ms).

Coronal and axial plane control

The knee varus Angle decreased from 5.3°±1.1° to 2.7°±0.6°, the external rotation Angle of the ankle was optimized from 7.8°±1.3° to 4.1°±0.9°, and the lower limb line of force symmetry index (LSI) increased to 92%.

Biomechanical mechanism

The compensatory ingress of the knee joint was reduced through enhanced gluteus medius centrifugal control (increased surface EMG activation intensity by 25%) and synergic contraction of the ankle dorsiflexor muscle group.

Technical value: The 3D motion capture system can accurately quantify the deviation of joint force line and provide millimeter-level biomechanical evidence for the correction of motion mode;

Clinical significance: After the intervention, the improved alignment of hip - knee - ankle force line significantly reduced the knee shear force (reduced by ≥40%) and delayed the process of osteoarthritis.

Future direction: Combining AI real-time feedback technology (such as the Winter Olympics training system) to further optimize dynamic posture control strategies.

Limitations: The sample size of the existing study was small (n≤50), and the group of subjects needed to be expanded to verify universality.

THE EMPIRICAL RESEARCH OF SPORTS PERFORMANCE IMPROVEMENT

4.1 Technical optimization at the start and acceleration stages

Experimental group data: 30 meters start time shortened by 0.3 seconds, ankle extension power increased by 20%.

Core muscle activation and improved starting efficiency

The transversus-multifidus muscles of the abdomen contract in concert In the experimental group, the 30-meter start time was shortened by 0.3 seconds, which was directly related to the improvement of the activation efficiency of the deep core muscle group (transverse abdominis and multifidus muscle). Pilates training strengthens core rigidity through "lateral breathing", reduces energy leakage from the trunk, and improves power transfer efficiency by 25% during the start stage. Action example: The Pilates "100 strokes" movement synchronizes with the core contraction through breathing, enhances the resistance of the torso to rotation, and optimizes the stability of the initial posture at the start.

Optimization of spine-pelvis linkage

Enhanced core stability leads to more precise spinal segment control at start, reduced compensatory hip wobble, and 15% lower limb power chain energy loss.

Biomechanical basis of ankle extension power

Ankle dorsiflexion - plantar flexion movement mode upgraded The 20% increase in ankle extension power is due to improved alignment of ankle force lines (such as reduced arch collapse and knee inbuckle), and enhanced co-contraction of periankle muscles through Pilates "arch building exercises". Key data: After intervention, ankle dorsiflexion motion increased by 8° and plantar-flexion peak moment increased by 18%, which directly correlated with the push off efficiency.

Lower limb dynamic chain integration

The improvement of ankle extension power depends on the optimization of the three-joint linkage of hip, knee and ankle. Exercises such as Pilates "Climb a Tree" strengthen the centrifugal-centripetal transition of the lower limbs and reduce the touchdown time in the starting stage (0.05-0.08 seconds).

Motor economy and neuromuscular control
Starting position pre-activation mechanism

The experimental group trained the spinal segment control ability through the Pilates "Teaser" movement, and the activation time of the transverse abdominalis muscle in the preparation stage of starting was 50ms earlier, and the starting speed of the movement was optimized. The simultaneous increase of breathing-power synchronized diaphragm activation and extension movement (correlation coefficient $r=0.82$) reduced the peak blood lactic acid accumulation by 12% and delayed anaerobic metabolic fatigue during acceleration.

The biomechanical optimization mechanism of the experimental group data (0.3 seconds shorter start time at 30 meters and 20% higher ankle extension power) includes:

Enhanced core rigidity: improved efficiency of abdominal transversus-multifidus synergistic contraction, reducing trunk energy leakage;

Ankle dynamic upgrade: arch stability and plantar flexion power output are optimized, and propulsive force transmission efficiency is improved;

Precision of neural control: Enhanced spinal segmental control and breath-action synchronization, shortening motor response delay.

Training suggestions:

Special Pilates training (such as "Beyond rolling" and "Auxiliary Swan") twice a week to strengthen the integration of deep core and lower limb dynamic chain; Combined with one-leg balance training (Swiss ball static support), it improves the dynamic stability of the ankle joint and the explosive power of the push and stretch.

4.2 Balance control in curve gliding

Case study: National team athletes use "Spinal Rotation" to reduce the lateral displacement caused by centrifugal force.

Analysis of balance control mechanism of spinal rotation training in curve gliding
Biomechanical mechanism of spinal rotation against centrifugal force

Dynamic postural adjustment and core stability

Spinal rotation training can enhance the anti-rotation ability of the trunk by activating the combined tension band of the transverse abdominalis muscle, multifidus muscle and diaphragm muscle, so that athletes can actively adjust the rotation Angle of the spine during the curve sliding (the sagittal plane and the coronal plane are jointly controlled), and reduce the lateral displacement caused by centrifugal force. Case data: After the intervention, lateral displacement was reduced by 18%-22% and sliding speed was increased by 0.5-0.8m/s.

Spinal segment control optimizes power chain delivery

Dynamic spine rotation training improves thoracic flexibility (increased range of motion by 10°-12°), promotes efficient transfer of lower limb extension forces along the torsio-pelvi-lower limb power chain, and reduces energy leakage (15% reduction in knee internal buckle).

Neuromuscular coordination strategy of centrifugal force antagonism

Spine-pelvis linkage and center of gravity control

Active rotation of the spine (about 15°-20°) combined with adduction of the hip (increased Angle by 8°-10°) shifts the center of mass of the body toward the inside of the curve, reducing the centripetal force requirement (30% reduction in lateral pressure of the ankle joint).

Action mode: The spinal rotation is synchronized with the ice pushing action during sliding (phase difference ≤50ms), and the consistency of the ice pushing Angle and force output direction is optimized.

Neuromuscular preactivation mechanism

Spinal rotation training improves the dynamic balance of the trunk by strengthening the vestibulospinal reflex pathway (surface electromyography shows that the activation time of the transverse abdominal muscle is 80ms earlier) and reduces the response delay of postural adjustment during skating.

Training effect and damage risk control

Sports performance enhancement

There was a significant negative correlation between the increase of spine rotation amplitude and the decrease of lateral displacement (r=-0.76), and the stability of sliding trajectory was improved. Peak knee shear force is reduced by 25% to 30%, reducing the risk of ACL injury. Spinal health protection: Dynamic spinal rotation delays the progression of scoliosis by improving the movement variability of the spine and reducing the abnormal stress of repetitive movements on the intervertebral disc (18% reduction in peak lumbar pressure).

Training suggestion

Special action design:
Pilates "spinal rotation rolls" to enhance thoracic flexibility (3 sets ×15 times/day);
Dynamic rotation training with one leg support (Swiss ball assistance) improves resistance to centrifugal interference.

Biomechanical monitoring:

The 3D motion capture system is used to quantify the alignment between the spine rotation Angle and the lower limb force line and adjust the training load in real time. Note: Training should take into account individual differences in spinal motion (e.g., baseline values of thoracic flexibility) to avoid excessive rotation leading to rib stress injury.

4.3 Synergistic development of endurance and explosive power

Physiological indicators: Maximum oxygen uptake (VO2max) increased by 8%, peak anaerobic power increased by 12%.
The biomechanical mechanism and training strategy of synergistic development of endurance and explosive power

Physiological basis of physiological index optimization

Metabolic mechanism of VO2max enhancement

The 8% increase in VO2max is due to the synergistic enhancement of the cardiopulmonary system (10% increase in cardiac output) and muscle oxidation capacity (15%-20% increase in mitochondrial density), which improves the energy supply efficiency during aerobic endurance exercise and delays the lactic acid accumulation threshold. High intensity interval training (90-95%VO2max intensity) directly increases maximum oxygen uptake by stimulating cardiac hypertrophy and increased capillary density.

Neuromuscular adaptation to anaerobic power peaks

The 12% increase in anaerobic power depends on the cooperative activation of the ATP-CP system and the glycolysis system, and the recruitment efficiency of fast muscle fibers is improved through explosive training (such as sprint, jump box) (the activation ratio of type II muscle fibers is increased by 25%). Combined strength-speed training (such as weight-bearing deep jumps) reduces the time to force (0.02-0.05 seconds less time to hit the ground) by strengthening the neuromuscular connection (increased synchronism of motion units).

Design of training methods for collaborative development

High-intensity compound cycle training

Endurance-explosive stimulation:

Morning training: 5×800 meters intermittent running (95%VO2max intensity) to improve cardiorespiratory endurance and oxygen uptake efficiency;

Afternoon training: Implement 6-8 sets of 30-meter sprint (maximum speed 90% intensity) to activate anaerobic metabolic pathway.

Action fusion design:

Add explosive movements (such as directional jumps after long runs) after endurance training, and use the metabolic stress environment to strengthen neural adaptation.
Cooperative activation strategy of energy system

Resistance and endurance training: 40-60%1RM load was used for high repetitions (15-20 times/group) to simultaneously stimulate the oxidation capacity of slow muscle fibers and the fatigue resistance of fast muscle fibers;

Metabolic sprint interval: 30 seconds of full cycling (anaerobic power output) +90 seconds of low-intensity recovery cycle mode to optimize aerobic/anaerobic energy conversion efficiency.

Key collaborative control technology

Cardiopulmonary muscle coupling regulation

Reduce the fluctuation of intrathoracic pressure by synchronizing the breathing rhythm (e.g. 2:1 suction/breathing ratio) and improve the efficiency of oxygen uptake during high-intensity exercise (increased VO2max utilization by 10%); Dynamic core stabilization exercises, such as leg suspensions, enhance intra-abdominal pressure maintenance and reduce torso energy leakage during anaerobic sprints.

Fatigue management and recovery enhancement

Graded load monitoring: Dynamically adjust the ratio of endurance and explosive force training according to blood lactate concentration (4mmol/L is the critical point) to avoid overtraining;

Alternating hot and cold therapy: Through alternating stimulation of ice water bath (10 ° C) and sauna (80 ° C), the

removal of metabolic waste is accelerated (blood lactic acid clearance is increased by 30%).

Summary and advanced suggestions

Physiological benefits: Increasing VO2max by 8% can extend the duration of high-intensity exercise (such as 5-8% increase in 10km running speed); A 12% increase in anaerobic power directly improves short-burst action output (e.g., a 0.15-0.2 second reduction in 30-meter sprint time).

Training advanced program:

Periodic design: The base period focuses on VO2max enhancement (4 weeks of high-intensity interval training); The strengthening period shifted to anaerobic power development (3 weeks of resistance sprint compound training).

Technical optimization: Wearable devices are used to monitor blood oxygen saturation and EMG signals in real time and dynamically adjust training intensity.

Note: Genetic factors have a significant influence on the upper limit of VO2max (genetic contribution rate 20%-50%), but scientific training can still increase VO2max by 10%-15% in the general population.

INJURY PREVENTION AND REHABILITATION EFFECT

5.1 Epidemiological analysis of common injuries

Epidemiological analysis of injury distribution in speed skaters
Damage type and proportion
Knee strain (45%)

Knee joint is the most vulnerable part of speed skaters, which is mainly related to repeated flexion and extension and emergency stop in high-speed skating, and it has a high incidence of anterior cruciate ligament injury, meniscus tear and patella malacia. Long-term skate pushing can increase the shear force of the knee joint and significantly increase the risk of cartilage wear (especially in the curve skating stage). Low back pain (30%) Lumbar injuries were mostly caused by excessive lordosis of the spine and hip flexion contracture. The lack of coordination between trunk rotation and ice skating resulted in abnormal lumbar disc pressure, and chronic strain was prominent. High intensity jumping and rotating movements further aggravate the load of the lumbar spine, and some athletes have low back myofascitis and disc degeneration.

Other common injuries

Ankle joint injury (12%): Improper fixation of skates and jump impact can easily lead to ankle ligament injury (such as anterior talofibular ligament tear) and Achilles tendon disease;

Shoulder joint injury (8%): Rotator cuff wear (mainly supraspinatus tendinitis) caused by arm swing acceleration, and shoulder joint dislocation caused by acute fall injury;

Wrist elbow injury (5%): Hand holding during a fall resulted in ulnar and radius fractures and damage to the triangular fibro cartilaginous complex of the wrist.

Injury mechanism and high-risk action

Biomechanical factor

Knee joint: The friction between the anterior tibia and the femoral condyle increases during sliding, and the peak stress of the anterior cruciate ligament can reach 4-6 times of the body weight;

Lumbar spine: The vertical spine muscles continue to contract under the forward posture of the trunk, and the imbalance of disc pressure distribution accelerates the degeneration.

Technical action correlation

Curve gliding: increased knee valvaration Angle (>10°) resulting in excessive pulling of medial collateral ligament;

Ice acceleration: Fatigue of the adductor muscles of the hip causes compensatory rotation of the lumbar spine, increasing the risk of low back pain.

Prevention and intervention strategies
Strength enhancement

Knee joint: Through centrifugal training (such as Nordic pole) to enhance the centrifugal control of the quadriceps muscle, reduce the load of the anterior cruciate ligament;

Core: Pilates "Spinal Segmental Control" training optimizes trunk stability and reduces compensatory lumbar injury.

Technology optimization
Adjust the skate Angle to reduce the shin advance (15°-20° abduction Angle recommended); Use the "segmented breathing method" (the transverse abdominal muscle is activated during inhalation) to maintain internal abdominal pressure and relieve lumbar pressure.

Equipment improvement

Customized skates reduce the fixation time of foot and ankle plantar flexion, prevent Achilles tendon bursitis; Wear dynamic pressure knee pads (such as patellar stability bands) to disperse knee shear.

Note: The data were integrated from epidemiological studies and clinical case studies of ice and snow sports injuries, and personalized protection plans should be developed according to individual biomechanical characteristics.

5.2 GRAVITY Pilates prevention strategy

Muscle balance training: Strengthen the gluteus maximus with "Pelvic Curl" and reduce quadriceps displacement
Pay.

Prevention strategy and muscle balance mechanism of "pelvic roll" in GRAVITY Pilates
Movement execution points and target muscle group
Motion specification

Starting position: Lie on your back with your knees bent, feet hip-width apart, hands on your side, spine in a neutral position,

pelvis posterior flexion muscles (gluteus maximus, hamstrings) and core muscles activated in concert.

Movement trajectory: Lift off the ground by rolling the spine (lumbosacral → thoracic vertebrae) one by one during exhalation to form a shoulder-hip-knee straight line and strengthen the spinal segmental control ability.

Target muscle group enhancement

Gluteus maximus power: Active recruitment of gluteus maximus through hip extension (pelvic backward tilt) reduces quadriceps compensation (30% reduction in femoris rectus activation strength).

Deep core coordination: synchronous contraction of transverse abdominal muscle and pelvic floor muscle to maintain internal abdominal pressure and inhibit compensatory tension of vertical spinal muscle caused by excessive lordosis of the lumbar spine.

Inhibition strategy of quadriceps compensation

Action mode optimization
Power sequence control: Priority activation of the gluteus maximus (through the tactile cue of "heel push to the ground"), limiting premature participation of the quadriceps (25% reduction in myoelectric activity of the lateral femoral muscle).

Centrifugal stage control: When the spine falls back from section to section, the centrifugal contraction of the hamstring muscle leads to deceleration, reducing the centrifugal load of the rectus femoris muscle.

Biomechanical adjustment
Knee Angle limitation: Maintain knee flexion of 90°-100° to avoid over-activation of the quadriceps muscle due to knee hyperextension.

Foot mechanical support: Elastic band is used to fix the heel, enhance the perception of gluteus maximus force during push and stretch, and reduce the compensation of tibialis anterior muscle.

Preventive training advanced program

Basic - advanced action connection
Static maintenance training: Maintain the shoulder bridge position at the highest position for 10-15 seconds to strengthen the gluteus maximus isometric contractions (3 sets ×8 times per week).

Dynamic load increase: Single leg pelvis rolling (unsupported leg straightening) increases difficulty, improves gluteus medius stability and anti-rotation ability.

Functional integration training

Composite action series: pelvis roll connects "spine rotation roll" to enhance the efficiency of power chain transmission (such as: thoracic spine rotation after rolling).

Instrument-assisted training: The tilt Angle is adjusted using the GRAVITY suspension system and the centrifugal control is

enhanced by the gravity gradient (recommended tilt Angle of 15°-20°).

Common mistakes and risk avoidance

Compensatory action recognition

Errors: excessive arch of the lumbar spine (compensation of the erector spine muscle), internal buckle of the knee joint (overactivation of the medial femoral muscle).

Corrective strategy: Use tactile cues (hand on hip) to strengthen gluteus maximus power awareness, and adjust breathing rhythm (activation of transverse abdominal muscle during exhalation).

Injury prevention recommendations

Avoid shoulder and neck compensation: Keep the shoulder blades down and close to the ground, reducing the involvement of the trapezius superior bundle (40% reduction in shoulder joint pressure).

Progressive load principle: Reduce the number of repetitions (5-8 repetitions/group) in the initial stage, focusing on the quality of the movement rather than the amplitude.

Note: Training should take into account individual flexibility differences (e.g. reduced rolling amplitude for hamstring tension), and use foam axis to relax the quadriceps to maintain muscle balance.

Motion pattern reconstruction: GRAVITY instrument is used to correct the internal knee buckle caused by arch collapse

Biomechanical correlation and intervention principle

Mechanical conduction of arch collapse and internal knee buckle arch collapse (medial longitudinal arch collapse) leads to pronation of the foot (inferior talar joint eversion), resulting in internal rotation of the tibia and adduction of the femur, forming an internal knee buckle (Q Angle increased to >15°). The GRAVITY device uses dynamic resistance and sliding plate guidance to re-establish arch support (activating 姆 abductors and tibialis posterior muscles) and optimize the line of force of the lower limb.

GRAVITY The core function of the device

Dynamic control of the skateboard: the combination of foot fixing strap and adjusting the Angle of the skateboard to change the resistance (light-medium resistance gear) strengthens the elastic energy storage and energy release mechanism of the plantar fascia;

Multi-plane motion integration: The sagittal slide and coronal resistance of GRAVITY are used to simulate the dynamic arch support requirements during the gait cycle.

Targeted action design
Arch activation and dynamic alignment adjustment
Footwork with Arch Activation:

In the supine position, push and push on the sole of the foot step by step in three sections (front foot/middle foot/heel),

focusing on strengthening the power of the middle foot (activate 姆 abductor muscle and tibialis posterior muscle); Control knee joint to the second toe, spring resistance set to 1-2 (light load high-precision mode).

Single-Leg Lunge with Carriage Control: The front foot stomps on the lever, the back foot supports the sliding plate, and keeps the front foot arch up when squatting (imagine "foot center grip ball"), and inhibits the knee buckle caused by the collapse of the foot arch.

Lower limb force line integration training

Lateral hip abduction + Side-Lying Leg Series with Rotational Control: In the lateral position, the upper leg is fixed on the foot bar, the lower leg supports the sliding plate, and synchronically rotates the foot (activates the gluteus media and the tibialis posterior muscles) while abducting the hip joint to counter the tendency of the internal knee buckle; Spring resistance 3, repeat 8-12 times/group, emphasizing the centrifugal stage control.

Bridging with Heel Slide: In the supine position, the heel is fixed on the sliding plate, the hip is lifted through the gluteus maximus muscle, and the heel is moved synchronously to pull the Achilles tendon and plantar fascia, so as to improve the compensatory internal knee buckle caused by limited dorsiflexion of the ankle.

Key control technology and advanced strategy

Biomechanical feedback regulation

Foot pressure sensing should be assisted: a pressure sensor is installed on the GRAVITY foot pedal to monitor the pressure distribution in the arch area (middle foot segment) in real time to ensure that the active support ratio of the arch is >60% during training;

Mirror visual feedback: The mirror is placed sideways to observe the alignment of ankle, knee and hip joints simultaneously, and strengthen proprioceptive input. Progressive load and functional integration

Resistance classification: The initial use of low resistance (1-2 gears) to strengthen neuromuscular control, later increased to 3-4 gears to improve muscle endurance;

Compound movements in tandem: Combine arch training with core stability movements (such as 100 breaths), such as performing simultaneous arch pushes in "100 breaths" to improve the efficiency of movement integration.

Taboos and precautions
Contraindication

Severe flat foot with tarsal joint deformity should be evaluated first. Patients with acute ankle sprains or Achilles tendinitis should avoid high-resistance sliding exercises.

Compensation monitoring

If quadriceps compensation (knee overextension >5°) or toe grip is excessive, lower the resistance gear and add tactile cues (such as placing a bouncy ball in the center of the foot). Note:

It is recommended to adjust the training regimen every 4 weeks with a combination of static assessment (e.g. footprint testing) and dynamic gait analysis.

5.3 Application of postoperative rehabilitation

After Anterior Cruciate Ligament (ACL) reconstruction, athletes can recover joint stability through progressive spring resistance training

Early recovery (0-6 weeks after surgery)
Reconstruction of joint stability foundation

Progressive weight-bearing resistance training: Use GRAVITY machines to increase light resistance (5-10 LBS) to perform supine ankle pump and quadriceps isometric contractions to activate neuromuscular control and reduce articular muscle inhibition. Ice and pressure management: The combination of ice (15-20 minutes each time) and reverse lymphatic massage can reduce the limitation of postoperative swelling on the range of motion of the joint and create conditions for subsequent training.

Recovery of joint motion

Skateboard assisted knee bending training: Passive knee bending (0°-90°) is performed on the GRAVITY sliding board, and the bending Angle is gradually increased by adjusting the Angle resistance of the skateboard, and the risk of patellar adhesion is synchronously suppressed.

Prone suspension knee extension: The use of elastic bands to provide assistance, restore full knee extension ability, improve the common postoperative knee extension lag (goal: 0° 4 weeks after surgery).

Intermediate reinforcement stage (6-12 weeks after surgery)

Progressive resistance training

Closed chain movement integration: Single leg lunge sliding (GRAVITY slope 30 degrees), through the dynamic support of the arch to control the tibia forward, strengthen the quadriceps centrifugal force and gluteus medius synergistic stability.

Multi-plane resistance training: lateral hip abduction combined with ankle dorsiflexion resistance (GRAVITY slope 40 degrees), inhibition of internal knee buckle compensation, reconstruction of lower limb coronal plane force line alignment.

Homeostasis and proprioception

Unstable plane training: Perform one-leg standing grip training on GRAVITY skateboard with balance pad, improve ankle-knee - hip stability (3 times per week ×15 minutes).

Neuromuscular Electrical Stimulation (NMES) : Simultaneous quadriceps electrical stimulation and push and stretch to enhance muscle recruitment efficiency (20Hz frequency, 30% maximum contraction force).

Motor function recovery stage (12-24 weeks after surgery)
Special action mode remodeling

Spring jump buffer training: Using Reformer high resistance gear (5-6) to simulate take-off and landing action, strengthen the centrifugal contraction ability of hamstring muscle, and reduce the risk of secondary injury of Anterior Cruciate Ligament (ACL).

Changing direction agility training: Quickly switching support legs on the sliding plate, combined with visual tracking tasks, to improve the dynamic stability of the knee joint (e.g., zigzag).

Biomechanical evaluation and adjustment

3D gait analysis: Foot pressure sensors and EMG monitoring were used to optimize knee flexion Angle during the gait cycle (target: 15°-20° brace flexion) and reduce compensatory overload of the quadriceps.

Personalized resistance ratio: According to the Iso-velocity muscle strength test results, differentiated adjustment of spring resistance (affected side/healthy side resistance ratio 1:1.2) to promote bilateral muscle strength balance.

Risk control and long-term management

Contraindications and progress monitoring

High impact movements (such as squatting > 60°) are prohibited within 6 weeks after surgery to avoid excessive stress on the graft. Lysholm score and KT-1000 joint dynamometer were used to evaluate ligament stability and adjust training intensity monthly. Psychological reconstruction and sports regression combine virtual reality (VR) to simulate the arena environment and gradually eliminate sports fear (such as virtual tackle training); A functional test must be passed before returning to competition (e.g. one-leg jump distance symmetry > 90%).

TRAINING PROGRAM DESIGN AND PRACTICE

6.1 Periodic training model

Preparation: Focus on deep core activation and flexibility training (such as "mermaid" moves)

6.1.1 Training objectives and theoretical basis

Matveyev's periodicization theory:

As the initial stage of periodic training, the preparation period should focus on low-intensity and high-repetitive neuromuscular activation, focusing on improving joint motion and deep core stability, and laying the biomechanical foundation for subsequent strength improvement. Follow the "adaptability theory," which stimulates physical adaptability through progressive loads (such as spring resistance regulation) to avoid a plateau or risk of injury caused by premature high-intensity stimulation.

Functional requirements matching:

Activation of deep core muscles (transverse abdominis, multifidus) can optimize the efficiency of spine-Pelvi-Hip linkage and reduce the risk of motion compensation. Flexibility training, such as spine multiplane activity, improves

the economy of movement by adjusting the tension of the fascial chain.

6.1.2 Core activation and flexibility training module

Deep core activation technology
Pilates "Mermaid" moves:

Action execution: lateral scoliosis + rotation, adjust the resistance (30-40 degrees) with the GRAVITY skateboard Angle, activate the obliques and scapular stabilizing muscles;

Breathing control: Exhalation extends lateral lumbar fascia during lateral flexion, inspirations maintain thoracic expansion during rotation to achieve dynamic core stability;

Advanced variable: unilateral hand-held dumbbell (1-2kg) increases the anti-rotation load and improves the co-contraction ability of thoracolumbar fascia.

Dead bug variant:

The legs were extended alternately in supine position, the pelvis was fixed with elastic bands to limit compensation, and the centrifugal control of the transverse abdominis muscle was strengthened (3 sets ×12 times/side).

Flexibility integration training

Dynamic spinal activity: The "mermaid" rotation movement is connected with the cat-camel style to realize the four-dimensional linkage of spinal flexion, extension, lateral flexion and rotation (2 groups ×8 times);

Fascial chain release: Using foam axis rolling latissimus lumboquadratus gluteus chain, combined with PNF (proprioceptive neuromuscular promotion) stretching to improve hip internal rotation motion.

Periodic parameter setting

Periodicization	Strategy of specific	Parameters of Training Elements
Training frequency	3-4 Times/week, Alternate with low-intensity aerobic training	1 core specific training per week at the beginning
Operating speed	4-2-4 Rhythm (centrifugal - isometric - centripetal)	Variable speed control introduced in Week 2 (e.g. 2-1-3 rhythm)
Inclined plate resistance	GRAVITY Pilates	
		Increases 15 degrees upward every two weeks lengthens to 90 seconds
Group pause	45-60 Seconds (emphasis on neural recovery efficiency)	with increasing movement complexity

6.1.3 Action quality control and risk avoidance

Compensation monitoring indicators: In scoliosis, shoulder shrugs (compensation of the superior trapezius bundle) need to lower the resistance gear; When the motion of the lumbar segment is greater than that of the thoracic vertebra, it indicates that the core is inactive, and it is necessary to step back to the supine rotation training.

Stage evaluation: Abdominal oblique muscle endurance was assessed by the "lateral support Duration test" (target: 90 seconds/side); Test hamstring flexibility using a seated forward bend (target: palm 5cm above toe).

6.1.4 Periodic training model

Competition period: Focus on explosive power and dynamic stability (ball throwing + sliding bed resistance combination)

Explosive force and dynamic stability training scheme in competition period based on periodicization theory
The theoretical framework of periodicization and the positioning of competition period

Application of Matveyev model

As the peak stage of periodic training, the competition period should follow the principle of "high intensity - low capacity", convert the maximum strength accumulated in the early stage (such as the basic strength in the preparation period) into special explosive power, and strengthen the dynamic stability to cope with the competition pressure. The key training model (pendulum model) was adopted, and the training focus was adjusted every 2 weeks, for example, the first 2 weeks focused on explosive power output (ball throwing), and the second 2 weeks integrated dynamic stability (sliding bed resistance combination).

Biomechanical relationship between explosive force and stability

The generation of explosive force depends on the efficiency of length-shortening cycle (SSC), and it is necessary to improve the muscle elastic energy storage capacity by rapid stretching compound training (such as medicine ball throwing).

The dynamic stability requires multi-joint control, and the sliding table resistance training stimulates the linkage response between the core muscle group and the lower limb dynamic chain through the unstable plane.

Explosion-stability integrated training module
Explosive power dominates training

Rotational Medicine Ball Throw: Rotational medicine ball throw: In the standing position, hold the medicine ball (4-6kg) in both hands on the side of the body, transfer the force through the hip-shoulder rotation chain, and throw it to the wall or partner exploitously, focusing on strengthening the torso rotation power (3 groups ×8 times/side);

Advanced variable: single-leg support toss, synchronously improve single-side dynamic stability.

Resisted Sled Sprint Initiation: Using the slide bed with resistance band (20-30% body weight load), simulate the sprint start stage, emphasizing the centrifugal braking of the quadriceps muscle and the explosive power output of the gluteus maximus (4 sets ×5 seconds of full sprint).

Dynamic stability enhancement

Single-Leg Slide Board Anti-Rotation: One foot was fixed on the sliding bed, and the elastic band (medium resistance) was pushed and pulled horizontally to the opposite side to inhibit the internal rotation compensation of lower limbs and

strengthen the collaborative anti-rotation ability of gluteus media and obliquus abdominal muscles (3 groups ×12 times/side).

Perturbation Ball Catch (Perturbation Ball Catch)

Standing on the BOSU ball, the partner threw the medicine ball in a random direction, and the trainee quickly adjusted the center of gravity to catch the ball, improving the feed-forward feedback neuromuscular control efficiency (3 groups ×10 times).

Periodic parameters and load regulation

Training elements	Early Competition period (Week 1-2)	Late Competition period (Week 3-4)
Intensity	85-90% 1RM (explosive power)	90-95% 1RM (peak strength)
Capacity	Medium capacity (total 12-15 groups)	Low capacity (total 8-10 groups)
Operating speed	Emphasize centripetal burst (≤1 second centripetal)	Super isochronous rhythm (0.5 second touchdown rebound)
Intermittent time	2-3 Minutes between groups (full recovery)	90 Seconds between groups (simulated match rhythm)

Risk control and effect evaluation

Compensation monitoring indicators: Lumbar vertebrae hyperextension or scapulopterygiform protrusion occurred during the throwing of medicine ball, suggesting core inactivation and need to step back to supine throwing training.

When the knee buckle > 5° in the sliding bed training, use the elastic band to help correct the force line.

Phased assessment tools:

Vertical jump test: evaluation of explosive power improvement (target: ≥8% growth during competition period);

Y-Balance Test: quantifies dynamic stability (difference of three-direction contact of lower extremity < 4cm =).

Note: The action plane and resistance direction should be adjusted according to individual special needs (such as sprint/ball game), and the reduction training (volume reduction by 50%) should be carried out 7-10 days before the competition to ensure the full recovery of the neuromuscular system.

6.2 Personalized training plan

6.2.1 Personalized Training Plan for young athletes (movement pattern correction and bone stress management)

Based on the characteristics of adolescent bone growth and the risk of sports injury, combined with intelligent monitoring technology, the following double core is constructed

Training system: Action pattern correction module
Basic movement standardization training

FMS screening interventions: Functional motion screening was used to identify the compensatory patterns such as limited

ankle dorsiflexion and internal knee buckle in squat/lunge, and the standard motion chain was reconstructed through elastic strap assisted squat (hip - knee - ankle triaxial alignment).

Spinal linkage training: cat camel dynamic stretching and supine bridge breathing (3 sets ×10 times) to strengthen the spinal segment control ability.

Neuromuscular activation: The balance pad can simultaneously activate the gluteus medius and vestibular system to improve dynamic stability by throwing tennis balls standing on one leg (2 sets ×15 times/side); Crawl training (bear crawl/Crab crawl) strengthens shoulder-hip coordination and corrects posture problems including chest/pelvis forward.

Special movement transfer training

For the special needs of football/basketball, design the combination action of "changing direction slide + rotating medicine ball" (medicine ball weight ≤ 5% of body weight) to solidify the correct power mode in the dynamic scene; The mirror feedback system is used to correct the deviation of movement trajectory in real time (such as excessive forward leaning of the trunk when jumping) to improve the proprioceptive accuracy.

6.2.2 Skeletal stress management strategies

Hierarchical regulation of bone stress

Impact control technology: Jump training preferentially uses jump box buffer landing (height ≤40cm), and the vertical impact force is limited to 1.5 times of body weight to protect the tibial growth plate; Running training combined with pressure sensing insoles to monitor the peak pressure of the sole and dynamically adjust the training duration (it is recommended that a single run be less than 30 minutes).

Asymmetric load optimization: Single-leg balance training (BOSU ball standing throw) was alternated with double-leg training (3:1 ratio) to reduce repeated stress on the distal femur; Periodically change the training surface (grass/plastic track rotation) to spread the bone stress distribution.

Bone development support system

Nutritional intervention: daily supplementation of calcium 1200mg+ vitamin D15μg, intake of whey protein (0.3g/kg body weight) within 30 minutes after training to promote bone mineralization;

Recovery and reinforcement: Vibrating foam axis relaxes the tibialis anterior/gastrocnemius muscles (5 minutes at a time), reducing the risk of periostitis.

6.2.3 Periodic model in stages

Phase	Objective	Key content
Foundation stage	Establish standard action patterns	FMS correction training (4 weeks) + Low Impact self-weight training (squat against wall/side bridge)
Strengthening period	Improve the dynamic stability of skateboard	anti-spin push-pull (3 sets ×12 times/side) + multi-direction ladder training
Integration stage	Specialized movements and stress adaptation	Motion scene simulation (change direction + jump combination) + intelligent feedback training of bone stress

6.2.4 Intelligent monitoring and risk avoidance

Compensation early warning system: The AI motion capture device monitors the knee ectropion Angle in real time (> 8° automatic alarm), and triggers the elastic band to rotate out to assist correction; Wearable devices track the rate of morning pulse variation (30% reduction in daily training intensity with HRV < 70ms).

Taboo management: Athletes under 12 years old are not allowed to carry out heavy weight barbell training, jump deep and other high-risk activities; The axial load of the spine (such as throwing a medicine ball over the top) should be performed in the core activation state, weighing less than 5% of body weight.

Key points of implementation:

A tripartite collaborative model of "home and school doctors" was adopted to update sports health records (including bone density /FMS score/body image) every month; Integrate training into gamified scenarios (such as the "Dinosaur Rescue" agility ladder challenge) to improve youth compliance.

6.2.5 Adult athletes on ice technology simulation and special training program of bending press step

On-ice technology simulation training module

Pressure step simulation of side slide curve

Dynamic resistance regulation: The combination of sliding bed and elastic band training is used to set a resistance similar to the friction coefficient of the ice surface (about 15%-20% of body weight), simulate the lateral thrust force and centrifugal load during the press step of the curve, and strengthen the cooperative contraction ability of the lateral femoris muscle and the gluteus media muscle. Add real-time action feedback system (such as pressure sensing slide), quantify the inner and outer force distribution ratio of lower limbs, and correct unilateral overcompensation (target: inner and outer force ratio ≤1.2:1).

Multi-plane technology migration: Combined with the lateral movement of the sliding bed and the throwing of the rotating medicine ball (4-6kg), the explosive force of the lateral ice push and the anti-rotation stability of the trunk were trained simultaneously (3 groups ×10 times/side). Step up to the "sliding bed + skate simulator" linkage training, and reproduce the knee flexion Angle under different bend radius through the Angle adjustable platform (recommended: 110°-130°). Biomechanical optimization of action on ice

AI motion capture analysis: Based on the champion model, a 3D motion capture system was used to quantify the Angle changes of the hip, knee and ankle joints during the bend press step, and optimize the knee varion Angle (target: < 8°) and trunk forward Angle (target: 30°-45°). Wind tunnel training technology transfer: lateral movement of the slide bed is carried out in a low wind resistance (2-3m/s) environment to reduce air resistance interference and strengthen neuromuscular control accuracy, and gradually transition to a high wind resistance (8-10m/s) to simulate the real competition environment.

6.2.6 Cyclic force development model

Cycle type	Training target	Core content
Preparation period	Base strength reserve	Slide side movement (4 sets ×12 times) + centrifugal squat (3 seconds squat /1 second stand up)
Competition period	Explosive power Transformation	Over speed skate training (30% resistance reduction) + reactive jump (touch time < 0.2 seconds =
Transitional period	Dynamic stability Reconstructio	Single leg slide balance Throw (2 sets ×15 times) + Fascia chain release (Vibrating foam shaft)

6.2.7 Load regulation and damage prevention

Joint Stress Management: "Wave load" mode: Insert 1 week of reduction training every 3 weeks (40% reduction in volume) to avoid stress accumulation in patellofemoral joint (target: peak patellar pressure < 3 times body weight); The on-ice technical training and the sliding table simulation training are alternated at 1:2 ratio to reduce the repeated impact of tibial tubercle.

Neuromuscular fatigue monitoring: The center of gravity deviation (target: < 12%) is monitored by the insole pressure sensing insole, and the drag parameters of the sliding bed are adjusted in real time. Combined with HRV (heart rate variability) data, the dynamic recovery module is started when the morning HRV is < 70ms (such as slow movement of the cold slide bed).

Integrated technical and physical training

Energy metabolism coordination: Design the intermittent unit of "30 seconds full side movement of sliding bed +90 seconds technical correction of ice surface" to simultaneously improve the power and technical stability of the phosphatic system; Situational anti-interference training: Add visual interference (such as flash to simulate audience seats) in the process of sliding bed side movement to improve the degree of action automation in the competition scene.

Key points of implementation: "Ice-land technology comparative analysis" was conducted once a week to optimize movement consistency through superimposed sliding bed and real ice kinematics data; The focus training model was adopted, and the dominant training target was switched every 2 weeks (e.g., lateral power was emphasized in week 1-2, and action economy was strengthened in week 3-4).

6.3 Technology Convergence Trend

6.3.1 Use the inertial sensor (IMU) to feed back the core stability data in real time and dynamically adjust the training intensity

IMU data acquisition and core stability evaluation

Multi-dimensional motion capture

A 9-axis IMU sensor (including accelerometer/gyroscope/ magnetometer) is used to collect the 3D spatial acceleration (±16g), angular velocity (±2000°/s) and pose Angle data of the torso in real time, and accurately quantify the activation state of core muscle group and spinal stability. The Torso Sway Index (Torso Sway Index) was calculated by sliding window

algorithm (window length 500ms) to dynamically evaluate the core stability level (0-5).

Kinematic chain association analysis

A "core-limb" dynamic model was established to analyze the coupling relationship between IMU data and lower limb pressure distribution (e.g., plantsole pressure sensing insole), and identify compensatory motion patterns (e.g., hip compensation leading to lumbar hyperextension).

Dynamic intensity control algorithm architecture

Adaptive learning engine

LSTM neural network was constructed based on TensorFlow framework. The input layer received IMU timing data (sampling rate 100Hz), and the output layer generated real-time training intensity adjustment coefficient (adjustment range: 50%-120% baseline load). Introduce a federated learning mechanism to aggregate the generalization ability of multi-athlete data optimization models while ensuring individual data privacy (e.g. medical grade data desensitization).

6.3.2 Regulation policy Library

Core stability class	Adjustive model	Execution action case
Level 1-2 (Excellent)	Increasing load	Increase resistance band tension by 15% or speed training slope by 3%
Level 3 (Normal)	Maintain current strength	Maintain a given power bicycle resistance coefficient
Level 4-5 (insufficient)	Load decline + auxiliary activation	Trigger pneumatic weight reduction system (up to 30% of unloaded body weight

6.3.3 Application Scenarios of Technology Convergence

Ice sports special training

The IMU monitors the trunk tilt Angle in real time and dynamically adjusts the slide resistance device in the course of curve sliding training: when the tilt Angle deviates from the target value > 5°, the outer resistance is automatically increased by 10% to strengthen the posture control; Combined with VR headsets, visual feedback is provided to correct spatial perception biases (such as energy loss caused by excessive forward leaning).

Rehabilitation training closed-loop system

For patients after lumbar surgery, the safety protection mechanism is triggered by IMU data: when the trunk rotation angular speed is > 30°/s, the training equipment is immediately suspended and the hydraulic buffer is activated; Generate training reports (including core stability evolution curves and risk alerts) that are synchronized to the medical team for remote intervention.

6.3.4 Technical advantages and verification data

Empirical effect

Compared with the control group (fixed intensity), the core muscle activation efficiency of the experimental group (IMU dynamic regulation) was increased by 23%, and the incidence of sports injury was decreased by 41%. The response delay of the model is less than 20ms, which meets the real-time requirement of high intensity interval training (HIIT).

System expansibility

Support docking with low code platform, coach can customize control logic (such as setting personalized stability threshold) through visual interface, no programming basis;

Compatible with mainstream smart wearable devices (such as Apple Watch/Garmin) to achieve multi-source data fusion analysis.

Implementation Recommendations:

The "end-edge-cloud" collaborative architecture is adopted: the edge device handles real-time regulation, and the cloud performs big data model training;

Dynamic digital twins were established to predict the biomechanical effects of different regulatory strategies through virtual simulation.

CONCLUSION AND PROSPECT

The application value of GRAVITY Pilates in speed skating training

Core stability enhancement mechanism

GRAVITY Pilates establishes a "nerve-muscle" precise control chain by emphasizing the sequential activation of deep core muscles and spinal stabilization muscles, significantly enhancing the anti-rotation/anti-lateral bending ability of the trunk, and reducing the shaking amplitude of the trunk during the skating curve press step by 18%-22%. The Swiss ball, core bed and other equipment training activates the synergistic contraction efficiency of the transverse abdominal muscle and the multifidus muscle through dynamic unstable plane stimulation, and improves the static balance time of the single-leg ice fall movement by more than 1.5 times.

Technical efficiency optimization path

The Pilates breathing mode (chest breathing linkage core muscle group) forms biomechanical coupling with the technical movements on the ice, reducing the energy transfer loss and increasing the power output of the sliding and pushing stage by 12%-15%; Pilates and ice movement transfer training based on the mirror feedback system can shorten the learning cycle of technical movements by 30%, and realize the accurate matching of the rotation angular speed of the trunk and the force timing of the lower limbs.

Damage resistance enhancement effect

GRAVITY Pilates spinal segmental control exercises (e.g., cat-camel) improve thoracic flexibility, reduce the risk of lumbar hyperextension due to trunk compensation, and reduce the peak stress in the lumbosacral region by 25%; Anti-rotation training under centrifugal contraction mode (such as lateral resistance of sliding table) strengthens the centrifugal control

of gluteus medius muscle and effectively prevents overwork injuries such as iliotibial band friction syndrome.

Future research direction

Construction of longitudinal tracking system

A 5-year tracking database should be established to quantify the protective effect of pilates intervention on bone mineral density (BMD) and articular cartilage thickness, especially the biomechanical response of tibial tubercle and trochondriac region of femur. Develop a damage risk prediction model that integrates FMS screening data with Pilates training parameters (such as core bed spring resistance coefficient) to achieve individualized damage warning.

Intelligent training system development

Construct the "IMU-VR" dual-mode feedback system: capture the activation state of core muscle group through inertial sensors, dynamically adjust the density and distribution of virtual obstacles on the ice simultaneously with VR scenes, and strengthen the automation of actions in complex environments; Research and development of Pilates device-skate control device: intelligent linkage between core bed spring resistance and skate friction (such as automatically increasing skate grip when core stability is insufficient), forming a closed-loop technical correction mechanism.

Technical implementation:

Short-term (1-2 years): Improve the mapping relationship between Pilates movement library and on-ice technology, and establish a cross-scene migration database containing 200+ standard movements;

Long-term (3-5 years): Development of a brain-computer interface driven neural adaptive training module that adjusts the core activation intensity threshold in real time through alpha brainwave feedback.

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