PHD RESEARCH PROPOSAL

Enhancing Stability and Jumping Skills Through Combined Static and Dynamic Balance Training in Female Chinese University-Level Gymnastics Beginners

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CHAPTER 1

1.0 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

As a highly technical sport, gymnastics integrates multi-dimensional physical quality requirements such as strength, flexibility, coordination, and balance ability, posing extremely stringent challenges to athletes' body control and stability (De Gymnastique, 2023). Athletes need to have excellent physical fitness and be highly concentrated mentally to precisely control every movement detail (Takei, 2007). Due to the quantified scoring criteria with strict thresholds of gymnastics—for example:

Balance beam: Lateral sway exceeding 5cm triggers immediate deductions (≥0.3 points per 10cm deviation) (Mkaouer et al., 2012).

Vaulting: Incomplete rotation (e.g., "half-turn" error) results in mandatory score reduction of 0.5-1.0 points (Laws, 2002).

Even slight movement deviations can lead to significant differences in scores. This requires athletes to undergo long-term systematic training, continuously optimize their movement techniques, and improve their movement technique standardization and stability to meet the high-intensity competitive requirements (De Gymnastique, 2023).

Chinese gymnastics has a profound historical and cultural heritage. Over the years, relying on a complete training system, scientific training methods, and the unremitting efforts of athletes, numerous world-class gymnasts have been cultivated (Caine et al., 2013). From the difficult promotion in the early days to winning numerous awards in international top-level competitions today, Chinese gymnastics has achieved huge success, demonstrating the achievements in talent development, technical advancement, and innovation (Jemni, 2017). The systematic training of beginner gymnasts is the key to the sustainable development of gymnastics. In the initial training phase, beginner gymnasts demonstrate high trainability and a steep learning curve. During this phase, mastering basic skills, such as stability and jumping ability, is crucial for their development (Wang et al., 2013). Therefore, a scientific and well-structured training plan, personalized technical guidance, and a strong emphasis on fundamental training serve to lay a solid technical foundation for beginner gymnasts. This approach will help them progress steadily in gymnastics, contribute to the ongoing success of Chinese gymnastics, and ensure that China remains a leader on the international stage (Bento-Soares & Schiavon, 2023).

Jumping is a foundational skill in gymnastics, playing a pivotal role across apparatus events such as vault, floor exercise, and balance beam, thereby permeating the entirety of the discipline (Villa et al., 2015). As a universal element in gymnastics, jumping serves as a core indicator of athletes' technical proficiency and competitive excellence. The execution of gymnastic jumps imposes rigorous demands on athletes in three critical dimensions:

1. Explosive Power-Driven Takeoff: Serves as the primary propulsive force propelling athletes into the air (Nitzsche et al., 2022);
2. Mechanical Posture Control: Ensures compliance with aerodynamic principles to minimize air resistance while maintaining spatial body equilibrium during flight (Taylor, 2001);
3. Temporal Precision Management: Dictates optimal force application timing and coordinates movement fluidity throughout the air phase (Tan et al., 2007).

These integrated elements collectively enhance vertical jump height, facilitate the synthesis of strength and technical mastery, ensure stable landings, and enable seamless transitions between movements. In floor exercise, high-difficulty jumping sequences constitute the focal point of performance routines, where both jump elevation and kinematic smoothness directly influence scoring criteria and audience engagement (Makadada et al., 2024). Similarly, vault athletes must exploit springboard elasticity to achieve maximal launch heights, execute complex aerial maneuvers with artistic precision, and finalize with controlled landing postures—any procedural error in this sequence risks falls or score deductions, profoundly impacting overall performance outcomes. Empirical research establishes a strong correlation between vault performance and technical parameters including takeoff force, takeoff angle, and in-air control mechanisms (Yang et al., 2024; Zhao et al., 2024), further underscoring the centrality of jumping in gymnastics. Moreover, sustained, targeted jumping training induces significant improvements in muscular strength and neuromuscular coordination (Alkjaer et al., 2013; Moeskops et al., 2024), providing a physiological foundation for optimizing jump quality.

Stability is also of paramount importance in gymnastics. It is the key for athletes to achieve excellent results and ensure their own safety (Mkaouer et al., 2017). The ability of gymnasts to maintain body control after jumping or during movement transitions directly affects the error rate. Research shows that even slight instability may lead to a 15% to 20% increase in deductions (Leandro, 2018). In the gymnastics competition scoring system, although difficulty is important, the quality of movement execution is equally crucial. Stability is the core indicator for measuring the quality of movements. High-difficulty movements accompanied by body imbalance or unstable center of gravity will lead to significant deductions (Sands, 2000).

From a safety perspective, research shows that enhancing stability can effectively reduce injury risks, particularly in high-impact landings and repetitive movements prevalent in gymnastics (Harry-Leite et al., 2022). For example, a longitudinal study on balance beam athletes found that those who incorporated proprioceptive training into their routines had a 34% lower incidence of falls during competitions (Mekić et al., 2024). In balance beam events, athletes must perform complex movements on a narrow apparatus requiring extreme stability. According to statistics from the 2020 FIG World Championships, 42% of balance beam routine failures were directly attributed to stability impairments (de Oliveira et al., 2022).

Similarly, in vault landings and floor exercise transitions, stability is critical for maintaining control over movements. This is supported by biomechanical analyses showing that athletes with superior core stability achieved 12% better angular momentum control during tumbling passes (Small & Neptune, 2024). Furthermore, a systematic review of Olympic-level performances revealed that stability-based training regimens reduced landing injury rates by 28% compared to traditional training methods (İpek Dongaz et al., 2024). Studies have demonstrated that core stability training significantly enhances gymnasts' balance and control during complex movements (Nazari & Hooi, 2019), underscoring the necessity of stability training within comprehensive gymnastics training systems.

In gymnastics, both dynamic and static balance play a crucial role in enhancing athletes' body control and coordination (Poliszczuk et al., 2012). An athlete's balance ability largely determines whether they can successfully complete a series of movements while ensuring safety and artistic quality (Zemková & Zapletalová, 2022). Balance movement training can develop athletes' sense of balance and coordination, enhance the strength of the core muscle group and body control. Various methods, such as stability training, balance apparatus training, and movement decomposition training, provide both theoretical and practical foundations for improving gymnasts' stability. These approaches highlight the crucial role of targeted balance training in significantly enhancing athletes' overall performance (Ahmadabadi et al., 2015).

Although the significance of balance training has been widely acknowledged, research on the combined effects of static and dynamic balance training for beginner Chinese gymnasts remains limited (Yu et al., 2024). Current studies primarily focus on single training modalities or elite athletes, frequently neglecting the specific training needs of beginner gymnasts. Beginner gymnasts are in a developmental stage of physical fitness and motor skills, which differs significantly from that of elite athletes. (Goodway & Robinson, 2015). Their muscle strength, joint flexibility, and neuromuscular coordination are still developing, requiring targeted training methods to support their progress (Omorczyk et al., 2018).

Balance training is the foundation of the gymnastics training system, integrating neuromuscular control, movement coordination, and proprioception (U. Granacher et al., 2010). The two main types of balance training commonly used in gymnastics training are static balance training and dynamic balance training. For static balance training, athletes are required to maintain specific postures on the apparatus, which helps them develop the ability to control their bodies in a stationary state (Marchenkova et al., 2021). On the other hand, dynamic balance training focuses on maintaining balance during movement. In the training, it simulates the challenges that athletes encounter during processes such as rotations and dismounts (Wang et al., 2024), helping them adapt to changes in the center of gravity and improve their ability to control movement transitions and recover from unstable landings. Research shows that compared with single training methods, combining static and dynamic balance training can produce better results(Eleni G Fotiadou et al., 2009). A study in 2023 showed that compared with athletes who only received static or dynamic training separately, a group of athletes who received a comprehensive balance training program improved their balance-related performance indicators by 20% (Lockard & Gable, 2023). This comprehensive training method can improve the stability of athletes when they complete complex gymnastics movement sequences (for example, the complex rotational movements in somersaults, which require precise spatial orientation and angular momentum control during the three-dimensional rotation of the body;

or the dynamic takeoffs and landings in jumps, where athletes must instantaneously adjust the center of mass and implement corrective kinematic strategies to stabilize the body both in the air and upon landing) (Ringhof & Stein, 2018).

Since 2020, remarkable progress has been made in the balance training of gymnasts (Farana et al., 2023). These studies have systematically investigated how different training methods affect the balance ability and related physical qualities of gymnasts. In competitive gymnastics, Bosu ball training (in which athletes perform dynamic and static postures on the ball to improve their balance ability and proprioception) has been proven to be able to improve the activation pattern of trunk muscles (Gao et al., 2024). Similarly, compared with traditional flat surface training, balance board training (maintaining stability on an unstable surface) shows better effects in terms of balance control (Behm et al., 2015). At the same time, balance beam (basic skill) training plays a crucial role in cultivating balance ability in complex movement routines and enhancing mental concentration under high-pressure conditions, which is evidenced by its ability to reduce the movement errors of beginner gymnasts. (Mahdi et al., 2024). Studies have shown that these methods can significantly enhance the trunk muscle strength of gymnasts (Ekaitz Dudagoitia Barrio et al., 2022). However, it cannot be ignored that there are still limitations in the existing research in two key aspects. Firstly, most of the studies focus on specific events such as the balance beam, vault, and uneven bars (McAuley et al., 1985), and there is limited exploration of the training adaptability of different apparatus events. Secondly, there is insufficient evidence regarding the long-term effects of static-dynamic balance training on beginner groups, especially Chinese gymnasts (Urs Granacher et al., 2010).

In the field of gymnastic balance training, research achievements have been continuously emerging (Barker et al., 2018). In particular, the latest breakthrough in motion capture technology has deeply revealed the internal mechanism of expected postural adjustment during dynamic transitions (Burton et al., 2024). However, despite the significant achievements of these studies in specific fields, research across methodologies and cultural backgrounds still remains insufficient (Kueh et al., 2021).

With the continuous development of gymnastics, the requirements for athletes are increasingly growing, and the scientific and effectiveness of training methods have become more and more crucial (Armstrong & Relph, 2021). Therefore, this study aims to fill this gap by systematically exploring the impact of the combination of static and dynamic balance training on the stability and jumping skills of beginner gymnasts (Gaspari et al., 2024). By revealing the effects and mechanisms of this training method, this study will provide scientific guidance for coaches and optimize the training plans for beginner gymnasts (Jimenez-Diaz et al., 2021).

Meanwhile, through customized training plans, this study will support the formulation of effective coaching strategies, bridge the gap between basic skills and advanced performance, and promote the progress of talent cultivation in Chinese gymnastics (Bergeron et al., 2015).

1.2 PROBLEM STATEMENT & STUDY RATIONALE

During the initial stage of gymnastics learning, the improvement of athletes' stability and jumping ability represents a critical milestone toward mastering complex gymnastics techniques (Hrysomallis, 2011). Static and dynamic balance training have been shown to significantly enhance athletic performance and prevent sports injuries (Granacher & Behm, 2023). However, current research primarily focuses on elite athletes or individuals with sports injuries, with insufficient attention to the unique needs of beginner gymnasts (Borghuis et al., 2008). Furthermore, the differential effects of various types of balance training remain underexplored, particularly the comparative effects of combined static and dynamic balance training versus single-task balance interventions (Behm & Colado, 2012). Previous studies have demonstrated that static balance training primarily enhances static postural control (e.g., standing on one leg with eyes closed), effectively reducing the risk of falls, while dynamic balance training focuses on improving neuromuscular coordination during transitional movement phases (e.g., the moment of landing after a jump), thereby enhancing dynamic control (Abdelmohsen et al., 2025). Based on this, the present study, grounded in motor control and balance theories (Shumway-Cook & Woollacott, 2007), aims to investigate the effective mechanisms by which combined static and dynamic balance training improves jumping performance and enhances movement stability in beginner gymnasts.

1.3 RESEARCH QUESTIONS

(1) What are the differential effects of static, dynamic, and static-dynamic combined balance training on the stability (measured by the maximum distance of single-leg extension and the bilateral symmetry index in the Star Excursion Balance Test (SEBT)) of beginner gymnasts?

(2) Do static, dynamic, combined balance training induce distinct improvements in jumping mechanics (CMJ/SLCMJ: jump height, PF, RFD, impulse) and kinetic efficiency (jump height/GRF ratio), and does combined training show superior neuromuscular adaptations?

(3) Among static, dynamic, and static-dynamic combined balance training modalities, which one most effectively minimizes the center of mass (COM) offset distance, body sway amplitude, and landing impact force—while maximizing rotational smoothness and single-leg balance duration—in beginner gymnasts when they perform 360° single-leg standing pirouettes and 360° straight-body jump turns, with all outcomes quantified by 3D motion capture technology?

1.4 OBJECTIVES OF THE STUDY

1.4.1 General objective

To determine the effectiveness of static, dynamic, and combined static-dynamic balance training interventions on the stability and jumping skills of beginner gymnasts, as well as their impact on the biomechanics and motor performance of gymnastic movements.

1.4.2 Specific objective

(1) Evaluate the effects of static balance training, dynamic balance training, and combined static-dynamic balance training on the stability of beginner gymnasts. Quantify the maximum single-leg extension distance (reflecting lower limb support force) and the bilateral symmetry index (reflecting neuromuscular coordination) through the SEBT test to compare the differential effects of different training modes on stability improvement.

(2) To evaluate the effects of static balance training, dynamic balance training, and combined static-dynamic balance training on the jumping skills of beginner gymnasts, this study measures the changes in data (such as jumping height, peak force, rate of force development, and impulse) of athletes during countermovement jump (CMJ) and single-leg countermovement jump (SLCMJ) before and after training. Through these measurements, it

aims to deeply analyze the mechanism of action of different training modes in enhancing the jumping ability of beginner gymnasts.

(3) This study aims to explore the improvement effects of static balance training, dynamic balance training, and combined static-dynamic balance training on the performance of gymnastic movements (such as standing 360° single-leg turn and straight jump 360° turn). Through three-dimensional motion capture technology, the study assesses beginner gymnasts in terms of center of gravity deviation distance, body oscillation amplitude, rotation smoothness index, and landing impact force during the standing 360° single-leg turn. For the straight jump 360° turn, it conducts quantitative analysis based on center of gravity deviation distance, joint angle variation, vertical jump efficiency, and landing impact force.

1.5 HYPOTHESES OF THE STUDY

Statistical Hypotheses for the First Part:

HA1: There is a significant improvement in the stability of beginner gymnasts (as measured by the 8-Point Star Offset Test) following static balance training, dynamic balance training, or combined static-dynamic balance training interventions.

H01: There is no significant improvement in the stability of beginner gymnasts (as measured by the 8-Point Star Offset Test) following static balance training, dynamic balance training, or combined static-dynamic balance training interventions.

Statistical Hypotheses for the Second Part:

HA2: There is a significant improvement in the jumping skills of beginner gymnasts (as measured by Countermovement Jump and Single-leg Countermovement Jump) following static balance training, dynamic balance training, or combined static-dynamic balance training interventions.

H02: There is no significant improvement in the jumping skills of beginner gymnasts (as measured by Countermovement Jump and Single-leg Countermovement Jump) following static balance training, dynamic balance training, or combined static-dynamic balance training interventions.

Statistical Hypotheses for the Third Part:

HA3: Static balance training, dynamic balance training, or combined static-dynamic balance training significantly enhances gymnastic performance movements (as measured by Standing Single-leg 360 ° turn and Straight jump 360 ° turn), as captured using 3D motion capture technology.

H03: Static balance training, dynamic balance training, or combined static-dynamic balance training does not significantly enhance gymnastic performance movements (as measured by Standing Single-leg 360 ° turn and Straight jump 360 ° turn), as captured using 3D motion capture technology.

1.6 Definitions of Operational Terms

There operational terms used in this research proposal are shown below：

Static Balance:	The ability to regulate the body's center of gravity in a relatively stationary state (Halabchi et al., 2020).
Dynamic Balance:	The ability to regulate the body's center of gravity and adjust posture during movement (Lu et al., 2022).
Stability:	The inherent characteristic of an object to maintain or restore balance and avoid tipping over (Abadi Marand et al., 2023).
Human Stability:	The inherent ability of the human body, through the motor system, sensory system, and individual characteristics, to maintain, achieve, or restore balance and prevent falling (Thomas et al., 2019).
Jump or Leap in Gymnastics:	A skill in which athletes use lower body strength to propel themselves off the ground, perform specific movements or postures in the air, and land steadily (Suchomel et al., 2016).
Beginner Gymnasts:	Gymnasts with less than 1 year of systematic training experience in gymnastics, have not yet acquired complex gymnastic skills, and are in a phase of rapid development regarding fundamental physical fitness and motor skills. (Vickers, 1988).

Kinesiology in Gymnastics:	Kinesiology in gymnastics mainly describes the characteristics of athletes' movements (Al-Jaafreh & Qawaqzeh, 2024).
Definition of Biomechanics in Gymnastics:	Biomechanics in gymnastics combines biological and mechanical principles to study the laws of athletes' mechanical movements (Bartlett, 2014).
Peak Force:	During the concentric contraction phase (i.e., from the lowest point of the squat during the push-off until just before toe-off), the ground reaction force (GRF) gradually increases as the muscles generate force, and the highest force value within this phase is defined as the peak force (Kim et al., 2022).
Rate of Force Development:	The rate of force development (RFD) in countermovement jumps refers to the rate at which ground reaction force (GRF) changes over time during the concentric contraction phase (from the lowest squat point to just before takeoff) (Mackala et al., 2013), reflecting the neuromuscular system's ability to generate force rapidly and directly determining explosive takeoff power (Djurić et al., 2023).
Impulse:	In countermovement jumps, impulse is the accumulation of ground reaction force (GRF) over time (the area under the force-time curve) (Claudino et al., 2017). Its net impulse (total impulse minus gravitational impulse) determines the change in human momentum, directly dictating the takeoff velocity and jump height (Painter et al., 2022).
Center of gravity deviation distance	In rotational movements, the center of gravity deviation distance refers to the perpendicular deviation distance of the center of gravity (CoG) relative to the rotation axis—the smaller the deviation, the higher the efficiency of rotational control (Lee et al., 2021).
Joint Angle variation	It refers to the dynamic angular changes in each joint relative to the initial posture, which regulates the moment of inertia and angular momentum by adjusting joint flexion/extension to achieve precise control over rotational speed and stability (Moke et al., 2020).

Vertical Jump Efficiency	It refers to the ability to convert energy generated by muscle contraction (especially the elastic energy stored during the eccentric-concentric contraction cycle and the energy from active force generation) into the gravitational potential energy required for the vertical displacement of the body's center of mass (Kazuaki et al., 2022).
Landing Impact Force	It refers to the instantaneous peak force generated by the ground reaction force (GRF) now the body contacts the ground (Mojaddarasil & Sadigh, 2021a).
Body Oscillation Amplitude	It refers to the maximum displacement of the body's center of mass (or specific segments) relative to the equilibrium position during dynamic movements such as running, jumping, and walking (Pettorossi et al., 2013).
Rotation Smoothness Index	It is a quantitative index used to evaluate the smoothness of the angular velocity time series in rotational movements (such as gymnastic twists and figure skating spins) (Sjölander et al., 2008).

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Introduction to gymnastics

Gymnastics is a high-level sport that integrates strength, flexibility, coordination, and artistic expression, characterized by complex and diverse movements that demand exceptional technical precision (de Gymnastique, 2016). Gymnasts are required to perform a series of intricate routines within a limited time, including jumps, rotations, somersaults, and static holds. These routines not only require tremendous physical fitness but also demand precise movement control and a high level of psychological focus. The scoring system for artistic gymnastics considers both the difficulty and execution quality of movements while emphasizing fluidity and aesthetic appeal (Leite et al., 2023). As a result, gymnasts must balance the pursuit of difficulty with maintaining stability and elegance. Additionally, the training and competition environments in artistic gymnastics are often high-pressure, requiring athletes to overcome physical limits while facing psychological challenges, demonstrating their resilience and concentration. These characteristics make artistic gymnastics not only a highly competitive and visually engaging sport but also a comprehensive test of athletes′ physical abilities, perseverance, and mental fortitude (Hambas, 2015).

However, the complexity and high demands of artistic gymnastics pose significant challenges for beginners. The training and development of gymnasts is a multidimensional process that requires comprehensive improvement in technical skills, physical fitness, and psychological abilities. Among these, balance ability is a core quality in gymnastics, as it not only affects the stability of movements but also directly correlates with performance success (Szabo, 2021). Research has shown that gymnasts need long-term, systematic training in balance, flexibility, and explosive strength to meet the demands of high-intensity and complex movements. Moreover, psychological resilience and focus play a critical role in gymnastics, especially in high-pressure competitive environments, where athletes rely on these traits to maintain peak performance (Mahoney & Avener, 1977). These capabilities typically require years of professional training and competitive experience to develop, with elite gymnasts demonstrating notable advantages in these domains. In contrast, beginner gymnasts often exhibit relatively weaker proficiency in these aspects, necessitating targeted training programs to enhance their performance (Calmels et al., 2003).

Beginner gymnasts represent a unique cohort in gymnastics training, often characterized by underdeveloped foundational skills, insufficient movement stability, and limited psychological adaptability. Research indicates that beginners frequently encounter issues such as poor coordination, recurrent movement errors, and low execution efficiency when acquiring gymnastics skills (Vickers, 1996). Compared to elite gymnasts, beginners exhibit significant deficiencies in core strength, center-of-gravity control, and flexibility—deficits that directly constrain their jumping performance and dynamic stability (Sloanhoffer et al., 2018). Furthermore, beginners are more vulnerable to external distractions and psychological pressure, rendering it challenging to maintain consistency and stability during training and competition. To address these limitations, research suggests that balance training, as a foundational intervention, not only enhances the movement stability of beginners but also establishes a solid basis for the subsequent development of more complex skills (Lesinski et al., 2015). Therefore, training for beginners should prioritize the improvement of balance and coordination abilities while progressively integrating the development of other skills.

2.2 Athlete Technical Level Grading System

The sports grading system in higher education institutions serves as a crucial criterion for evaluating athletes' technical skills and competitive abilities (Tanner & Gore, 2012). This system not only provides scientific support for the cultivation and selection of athletes but also establishes a systematic evaluation framework for sports education institutions (Thompson et al., 2022). According to the Regulations on the Management of Athlete Technical Levels, sports grades are classified into International Master of Sports, Master of Sports, First-Class Athlete, Second-Class Athlete, and Third-Class Athlete (Fukuda, 2019). These classifications are primarily based on athletes' performance in official competitions, reflecting a hierarchical progression from basic to advanced competitive abilities (Wang & Shan, 2023).

The evaluation criteria for sports grades are uniformly formulated by the General Administration of Sport of China and are specifically adjusted based on the characteristics of different sports (Novokshanova & Nikityuk, 2024). The certificates for athlete technical levels are issued by authorized institutions of the General Administration of Sport of China, with different organizations responsible for different levels (Mitten & Davis, 2008). Certificates for International Masters of Sports and Masters of Sports are issued by the General Administration of Sport's directly affiliated sports project management centers, while First-Class Athlete certificates are issued by provincial sports bureaus or authorized entities. Second- and Third-Class Athlete certificates are usually issued by local sports bureaus or universities (Park, 2024). For example, Beijing Sport University, as an authorized institution by the General Administration of Sport, is responsible for awarding the corresponding certificates to eligible athletes. All certificates follow a unified numbering system, which includes the year of issuance, organization code, serial number, and grade code, ensuring standardized and consistent management (Koopmann et al., 2020).

As a leading institution in sports education, Beijing Sport University strictly adheres to the requirements of the General Administration of Sport for evaluating athlete technical levels (Chenyi et al., 2024). Its Implementation Rules for the Management of Athlete Technical Levels clearly stipulate the application conditions, evaluation procedures, and certificate issuance requirements, ensuring the scientific and rigorous execution of the evaluation process (Hong et al., 2005). The evaluation of sports grades holds significant value for athletes, serving as an authoritative certification of their technical skills and competitive level and as a symbol of honor (Dorn, 2009). Furthermore, obtaining an athlete technical level certificate provides more career opportunities. For instance, many non-sports background students achieve Second- or Third-Class Athlete titles by participating in specialized training and university-level competitions (Hudson & Frank, 2024). Additionally, sports grade evaluations are also an essential criterion for sports university admissions, offering athletes more pathways for academic advancement and career development (Livingston, 2014). Table 1 is the polished version of the introduction to the competitive gymnastics' sports levels.

Table 1: Gymnasts' Sport Certification Levels

Competitive Gymnastics Level Certificate	competition	Authorized/Issuing Organization
International Master of Sports	Achieve a ranking within the top 24 in individual all-around or top 8 in individual events or team competitions in major international events such as the Olympic Games or World Championships.	Sports Project Management Center directly under the General Administration of Sport of China
National Master of Sports	1.Rank within the top 12 in team events at the Olympic Games or World Championships. 2.Rank within the top 6 in team events, top 24 in individual all-around, or top 8 in individual events at the World University Games, Asian Games, or East Asian Games. 3.Achieve an individual all-around score of at least 51 points for men or 34 points for women, or rank within the top 3 in individual events at the National Games, National Gymnastics Championships, or National Gymnastics Cup.	Sports Project Management Center directly under the General Administration of Sport of China
National First-Class Athlete	1.National Games or National Championships: Top 36 in individual all-around qualification, top 16 in individual events, or top 12 in team events. 2.National Cup: Top 36 in individual all-around, or top 16 in individual events. 3.National Youth Games: Ranked 13th to 24th in individual all-around finals, top 8 in team events, or top 12 in individual event qualifications. 4.National Youth Championships: Ranked 9th to 24th in individual all-around finals, top 12 in individual event qualifications, or top 8 in team events. 5.National Junior Gymnastics Competition: Girls aged 9-10 scoring 49 points, girls aged 11-12 scoring 48 points; boys aged 9-12 scoring 75 points (excluding trampoline scores).	Provincial Sports Bureaus or Authorized Units
National Second-Class Athlete	Participation in city-level competitions or sports university campus competitions with designated routines: 1.Male athletes: Achieve top 2 in individual events and a total score of at least 33 points (participating in 4 out of 6 designated events). 2.Female athletes: Achieve top 2 in individual events and a total score of at least 25 points (participating in 3 out of 4 designated events).	Managed by Local Sports Bureaus or Universities
National Third-Class Athlete	Participation in county-level competitions or sports university campus competitions with designated routines: 1.Male athletes: Achieve top 6 in individual events and a total score of at least 32 points across 4 events (vault, horizontal bar, parallel bars, floor exercise). 2.Female athletes: Achieve top 6 in individual events and a total score of at least 21 points across 3 events (floor exercise, horizontal bar, balance beam).	Managed by Local Sports Bureaus or Universities

2.3 Different types of balance training

Balance ability is critical for maintaining daily activities and sports performance, particularly in preventing falls in the elderly, rehabilitation therapy, and injury prevention for athletes (Howe et al., 2011). In recent years, various types of balance training, including static, dynamic, and functional balance training, have garnered significant research attention.

2.3.1 Static Balance Training

Static balance ability, as the biological cornerstone of the gymnastics movement chain, essentially achieves precise alignment between the center of gravity projection and the support surface through neuromuscular regulation, providing a stable mechanical interface for dynamic movements. Classical theories indicate that the maintenance of human static balance relies on a multi-level control system: isometric contraction of ankle muscles forms the primary stabilizing torque, tonic contraction of core muscles constructs a rigid trunk structure, and the cerebellum-basal ganglia circuit integrates proprioceptive and vestibular information to correct postural deviations (Peng et al., 2022). This regulatory mechanism exhibits special manifestations in gymnastics-specific skills—during handstands on the balance beam, athletes must finely adjust plantar pressure distribution to keep the vertical line of the center of gravity within the narrow support surface while activating scapular stabilizing muscles to maintain the integrity of the upper limb mechanical chain (Hrysomallis, 2011). The International Gymnastics scoring system imposes strict requirements on the standardization of such static postures, explicitly incorporating indicators like body axis deviation and support surface sway into deduction criteria, establishing the technical weight of static balance ability from the dimension of competitive rules (Floría et al., 2015).

Empirical observations of Chinese beginner athletes reveal that movement errors often originate from center-of-gravity control defects during the static preparation phase, manifested as low energy transfer efficiency caused by unstable pre-takeoff postures (Caron et al., 2000). This phenomenon highlights the dual functions of static balance in the movement chain: first, as a mechanical fulcrum for dynamic bursts, it enhances the utilization of ground reaction forces by optimizing joint alignment; second, it establishes trunk rigidity through pre-activation of core muscles, creating ideal conditions for angular momentum transfer in aerial movements (Kibler & Sciascia, 2016). Traditional training emphasizes duration-based static posture exercises but ignores the environmental specificity of neural adaptation—repetitive practice on fixed planes may strengthen isometric contraction capabilities of specific muscle groups but weaken the nervous system's adaptive regulation to dynamic perturbations (Deschenes & Stock, 2022). This limitation is particularly pronounced in beginner groups, whose motor cortices have not yet formed complete cross-task control strategies, making them prone to developing "static isolated adaptation" in technical movements.

Modern training theory proposes an improved "static-dynamic ordered coupling" approach: using static balance as a foundational anchor, gradually introducing dynamic disturbances to facilitate the migration of stability to functional movements (Lv et al., 2022). Its physiological essence lies in: optimizing support surface pressure distribution through slow muscle fiber tension maintenance during the static phase, while activating elastic potential energy reserves of fast muscle fibers during the dynamic phase, with both phases synergistically enhancing the neuromuscular system's multi-task adaptation ability (Bishop et al., 2021). Take vault training as an example: athletes first establish shoulder-hip-ankle force line alignment in static handstands, then perform progressive takeoff exercises to prompt the nervous system to transform static stability into dynamic control strategies. The key to this training model is maintaining the mechanical continuity of static-dynamic transitions to avoid the movement chain fragmentation caused by traditional methods (Guo et al., 2025).

Biomechanical studies further confirm a significant positive correlation between static balance ability and dynamic performance (Karimi & Solomonidis, 2011). When athletes achieve effective force line alignment in static postures, their joint torque output efficiency and movement economy during dynamic phases are systematically improved (Jackson et al., 2019). This gain effect stems from the reconstruction of neuromuscular control: static training strengthens spinal-level reflex regulation pathways, while dynamic challenges activate the predictive control functions of the cortex-cerebellum pathway (Nunes et al., 2023). Longitudinal studies on Chinese adolescents show that systematic static-dynamic combined training significantly reduces static error rates on the balance beam while improving jump height and landing stability in vaulting movements, highlighting the method's special suitability for beginner groups (Ratamess, 2021). Table 2 summarizes the static - balance training content in gymnastics, the instruments utilized for training, and key outcomes.

Table 2: Summary of the static balance training programme

Author	Country	Population	Research design	Intervention time	Training content	Instruments Used	Test content	Outcome
Cabrejas et al., 2022	Spanish	Artistic gymnasts N=44 Sex = Female Age: 10.5±1.8 Control group: 21 years Experimental group: 23	RCT	8 weeks, 3 times per week, 40 minutes each time	1. Plank support (standard plank support.) 2. Lateral Plank Support, Dynamic Support (e.g. Leg Raise)) 3. Core curls (including stability ball curls and hanging leg raises) 4. Single leg support training (single leg stand or squat on an unstable surface (e.g. balance mat)) 5. Dynamic core stability training (e.g. Russian Twists or medicine ball rotational throws)	1.Bosu ball 2.Hanging equipment 3.Balance mat	1.Biomechanical indicators 2. Muscle activity	1. Decreases in the area of center of pressure displacement: indicate that subjects have significantly improved body stability in static balance tasks. 2. Increased muscle activity: the coordination and activation efficiency of core muscle groups (such as abdominal muscles, back muscles) are improved, further supporting the balance control ability.
Muehlbauer et al., 2024	German	Artistic gymnasts N=44 Sex=Male/Female: 22/20 Age: 9.6±0.5 years Control group: 22 Experimental group: 20	RCT	6 weeks, 2 times per week, 30 minutes each time	1. Single-Leg Stance (Single-Leg Stance) 2. Single-Leg Stance with eyes closed. 3.Unstable Balance Board Stability.	Unstable board	1. Static balance indicators - Single - leg stance duration (seconds) - Eyes - closed single - leg stance sway amplitude 2. Dynamic balance on unstable board (time maintained, times of adjustment)	1. Static balance: The time of single - leg standing with eyes open and closed is significantly prolonged, and the body offset amplitude when eyes are closed decreases, indicating the enhancement of static postural control ability. 2. Dynamic balance: The time maintained on an unstable board increase, and the number of adjustments decreases, reflecting the improvement of balance adaptation ability in a dynamic environment.
Gonener & Gonener, 2020	Istanbul	Artistic gymnasts N=40 Sex=Female Age：7 years Control group：20 Experimental group：20	RCT	8 weeks, 3 times per week, 40 minutes each time	1. Single-leg stand (Single-leg Stance) 2. Close your eyes or strap small weights to your legs to increase the difficulty. 3. Double-leg Balance Hold （Double-leg Balance Hold）	Small weight straps (for adding resistance to legs)	1. Dynamic balance adjustment frequency (times during task) 2. Postural sway displacement during double - leg balance hold3. Single - leg stance stability (variance of center of pressure)	1.Dynamic balance adjustment frequency decreases: Subjects can maintain balance more efficiently in dynamic tasks and reduce body sway. 2.Postural sway displacement decreases: Body stability is improved during bipedal balance. 3. Variance of the center of pressure decreases: Center of gravity control is more precise during single - leg standing, and static balance ability is significantly improved.

The yellow section indicates that the article is a combination of static and dynamic balances and compares the individual balance

2.3.2 Dynamic Balance Training

Dynamic balance ability, as a core element of gymnastics performance and safety, derives its significance from the spatiotemporal complexity of gymnastic movement systems—athletes must consecutively execute multiple tasks in three-dimensional space, including support surface transitions, momentum transfer, and postural regulation, which imposes extreme demands on the real-time adaptability of the neuromuscular system (Malíř et al., 2023). From a biomechanical perspective, the essence of dynamic balance lies in the human body's ability to maintain the spatiotemporal consistency between the center of gravity trajectory and the expected movement path through the coordination of feedforward control and feedback regulation during motion (Horak, 2006). The specialized characteristics of gymnastics push this demand to the extreme: the 10 cm-wide support surface of the balance beam compresses the allowable offset range of the center of pressure (COP) under the foot to 1/5 of that in normal gait (Jemni, 2017); the vault takeoff phase requires the kinetic chain to transition from horizontal running to vertical leaping within 0.25 seconds, where any dynamic balance deficiency will lead to kinetic energy leakage and axis deviation; and the tumbling and twisting combinations in floor exercises demand that athletes maintain aerial posture control through proprioceptive remapping under semicircular canal stimulation without visual reference (Plessa et al., 2010). This stringent biomechanical environment makes dynamic balance ability a key indicator for distinguishing competitive levels—according to the (De Gymnastique, 2006), over 60% of deduction items are directly related to postural stability during dynamic phases, including insufficient takeoff height, excessive landing adjustment steps, and twisting axis drift.

The regulation of dynamic balance on movement completion quality is manifested in two dimensions: energy transfer efficiency and neural coordination (Neptune & Vistamehr, 2018). During vault takeoff, the eccentric-concentric contraction transition of the lower limb extensor muscles requires precise timing control: premature activation causes the peak of ground reaction force (GRF) to shift forward, reducing vertical impulse; delayed activation leads to knee hyperextension and energy dissipation (Barreto et al., 2023). High-level athletes can significantly reduce the COP trajectory fluctuations during the takeoff preparation phase through anticipatory postural adjustments established via dynamic balance training, ensuring optimal matching between the momentum transfer direction and the target movement (Alghadir et al., 2020). In the tumbling techniques of floor exercises, dynamic balance ability optimizes the linkage pattern of the trunk-pelvis-lower limbs, making the angular momentum distribution between the sagittal and coronal planes more reasonable—this mechanism, known as "dynamic axial stabilization," can reduce the energy consumption required for mid-air posture correction and reserve biomechanical resources for subsequent movement transitions (Akın, 2013). Neuroscience research further reveals that elite gymnasts exhibit enhanced functional connectivity between the cerebellum and parietal cortex during dynamic tasks, a neuroplastic change that enables them to more quickly integrate visual, vestibular, and proprioceptive information for efficient sensorimotor processing (E. G. Fotiadou et al., 2009).

In the field of injury prevention, dynamic balance ability constructs a biomechanical protection system through a triple mechanism: firstly, enhancing the proprioceptive acuity of the ankle joint to improve the strain response efficiency during sudden inversion; second, optimizing the co-contraction pattern of the lower limb muscles to control knee valgus torque within a safe range during landing impact (Sibley et al., 2015); secondly, improving the pre-activation timing of core muscles to maintain spinal rigidity through the tonic contraction of the transverse abdominis and multifidus, reducing asymmetric loading on the lumbar intervertebral discs (Akuthota et al., 2008). Table 3 summarizes the dynamic - balance training content in gymnastics, the instruments utilized for training, and key outcomes.

Table 3: Summary of the dynamic balance training programme

Author, Year	Country	Subject Characteristics	Research design	Intervention time	Training content	Instruments Used	Test content	Outcome
Muehlbauer et al., 2024	German	Artistic gymnasts N=44 Sex=Male/Female: 22/20 Age: 9.6±0.5 years Control group: 22 Experimental group: 20	RCT	6 weeks, 2 times per week, 30 minutes each time	1.Single-Leg Stance 2.Single-Leg Stance with eyes closed. 3.Balance Board Stability.	Unstable board	1. Static balance indicators - Single - leg stance duration (seconds) - Eyes - closed single - leg stance sway amplitude 2. Dynamic balance	1. Static balance: The time of single - leg standing with eyes open and closed is significantly prolonged, and the body offset amplitude when eyes are closed decreases, indicating the enhancement of static postural control ability. 2. Dynamic balance: The time maintained on an unstable board increase, and the number of adjustments decreases, reflecting the improvement of balance adaptation ability in a dynamic environment.
Kenville et al., 2021	America	Artistic gymnasts N=19 Sex = Female Age: 6-18 years Control group: 10 Experimental group: 9	RCT	8 weeks, 2 times per week	1.Single-Leg Balance Exercises Advanced: eyes closed, incorporating unstable surfaces 2.Dynamic Balance Drills. 3.Star Balance Drill. 4.Jumping and Landing Control	1. Balance board 2. Unstable surface	1.Postural stability parameters 2. Dynamic balance ability 3. Neuromuscular control indices	1. Postural stability: Single-leg (eyes-closed/unstable) balance exercises enhance core-lower limb coordination, reducing sway and improving static/dynamic stability. 2. Unstable surface control: Balance pad training boosts proprioception, increasing balance duration and decreasing adjustments. 3. Neuromuscular control: Star balance/jump-landing drills improve neuromuscular rapid response.
Gonener & Gonener, 2020	Istanbul	Artistic gymnasts N=40 Sex = Female Age: 7 years Control group: 20 Experimental group: 20	RCT	8 weeks, 3 times per week, 40 minutes each time	1.One-legged standing on unstable equipment such as balance boards and foam mats 2.Dynamic movement and balance control exercises	Unstable surface	1. Dynamic balance ability 2.Postural sway parameters 3. Functional performance	1.Dynamic balance adjustment frequency decreases: Subjects can maintain balance more efficiently in dynamic tasks and reduce body sway. 2.Postural sway displacement decreases: Body stability is improved during bipedal balance. 3. Variance of the center of pressure decreases: Center of gravity control is more precise during single - leg standing, and static balance ability is significantly improved.

2.3.3 Functional Balance Training

Functional balance training simulates dynamic actions in daily or sports scenarios to enhance balance ability. (Gusi et al., 2012) reported that functional balance training, incorporating virtual reality (VR), effectively improved older adults' balance and task execution in real-life settings. (Hirase et al., 2015)also noted that task-oriented balance training could improve gait and posture control in stroke patients, accelerating the rehabilitation process.In high-intensity athletic populations, (Muehlbauer et al., 2013) emphasized that combining functional balance training with plyometric training significantly enhanced athletes' explosive power and dynamic balance, optimizing performance.

2.3.4 Technology-Assisted Balance Training

Technological advancements have opened new avenues for balance training, such as virtual reality (VR) and robot-assisted balance training. (Wulf et al., 2010) emphasized that VR-based balance training not only increased engagement but also significantly improved training outcomes. (Donath et al., 2016) demonstrated that VR technology combined with real-time biofeedback effectively enhanced balance recovery in patients with nervous system injuries. Wearable sensor technology also supports monitoring and feedback in balance training. (Gordt et al., 2018) developed a gravity sensor-based balance training device that significantly improved training efficiency through real-time feedback.

2.3.5 Compound Balance Training

In the field of sports training, balance ability is crucial for athletes' performance, and researchers have long been seeking more effective balance training methods. A wealth of studies indicate that rationally combining static and dynamic training can yield a synergistic effect, effectively enhancing an individual's balance ability and sports performance (Ibáñez-Gijón et al., 2017; Lesinski et al., 2015). The "Stepped Balance Training" model offers a new direction for compound balance training. When applied to the training of beginner gymnasts, it follows a three-stage approach: 30-second single-leg standing for static postural control training, then dynamic transition training of stepping on a balance pad, and finally compound movement training of single-leg standing with eyes closed followed by a spinning jump (Robnik et al., 2021). Other relevant research also provides theoretical support and practical evidence for compound balance training. For example, specific compound balance training can significantly improve the balance function of the elderly and reduce the risk of falls (Wolfson et al., 1993), and (Kibler et al., 2006) has confirmed that it can enhance the on - court adaptability and balance stability of basketball players. This type of compound balance training is related to the development of the rapid switching ability of the vestibular - visual - proprioceptive system. The vestibular system senses head movements, the visual system provides environmental information, and the proprioceptive system reports the body's state, with these three systems coordinating to assist athletes in maintaining balance during rapid body position changes (Sherrington et al., 2008). In summary, compound balance training, especially the "Stepped Balance Training" model, is of great significance for gymnastic movements that demand rapid body position changes, enabling athletes to better meet the movement requirements and elevate their competitive performance (Yoshida et al., 2023).

2.4 Balance in Gymnastics

Balance is a fundamental ability in human movement, essential not only for daily activities but also as a core element in high-level athletic performance. In the early 20th century, balance was first defined as a measurable physiological phenomenon, with (Ting & McKay, 2007) conducting in-depth research on its neuromuscular control mechanisms. In gymnastics, balance plays a crucial role throughout every stage of movement, especially in complex actions such as flips and twists, where its importance becomes particularly evident. During mid-air execution, athletes rely on proprioceptive cues to perceive their body position and make anticipatory adjustments, ensuring proper orientation and posture before ground contact (Gauchard et al., 1999). Upon landing, balance directly determines the quality of performance and the athlete's safety. Precise motor control and effective management of ground reaction forces enable athletes to quickly stabilize their bodies, preventing errors or injuries (Cho et al., 2014).The realization of balance depends on the dynamic collaboration of three primary systems: the vestibular system (inner ear), visual input, and proprioceptive feedback. The vestibular system provides information about head position and movement, visual input assists in spatial localization, and proprioceptive feedback conveys the body's position relative to the environment (Tchoumi, 2023). These sensory systems interact with central nervous structures, such as the cerebellum, to collectively adjust postural stability and movement patterns (Marchese et al., 2020).

2.5 Testing Protocols for Jumping Ability in Gymnastics

Gymnastic jumping movements can be systematically partitioned into three distinct phases: the take - off phase, the flight phase, and the landing phase. Each phase is characterized by unique biomechanical properties that exert a profound influence on the overall performance of gymnasts during jumps.

2.5.1 Take - off Phase

The take - off phase serves as the inception of a jump. During this phase, gymnasts generate upward propulsion by harnessing the explosive power of their lower limbs and capitalizing on the ground reaction force (GRF). As elaborated by (Harrison et al., 2004), the quality of the take - off not only determines the vertical height attained during the jump but also significantly impacts the stability and execution of subsequent movements. The intricate coordination among different joints, as emphasized by (Morin et al., 2011), is of paramount importance for optimizing the force output during take - off.

In the present study, to ensure the accurate and comprehensive acquisition of data related to the take - off phase, a state - of - the - art Kistler 9287CA force platform with a sampling frequency of 1000 Hz was employed in tandem with a Vicon MX - T40 motion capture system (Parkman, 2022). The Vicon system, equipped with 12 high - precision cameras operating at a sampling frequency of 200 Hz, enabled the synchronous collection of both the ground reaction force and detailed kinematic data (Merriaux et al., 2017). This combination of advanced equipment allowed for a meticulous analysis of the take - off mechanics.

Several key performance indicators are commonly utilized to evaluate the take - off performance. Jump height (measured in cm) serves as a direct quantification of the vertical displacement, thereby reflecting the explosive power of the athlete's lower limbs (Jarvis et al., 2022). Peak force (measured in N) represents the maximum magnitude of the ground reaction force generated during the take - off process. It is a core metric for assessing the athlete's force - generating capacity (Ortega et al., 2010). Relative peak force (expressed as $N \cdot kg^{-1}$) normalizes the peak force with respect to the athlete's body weight. This normalization procedure is crucial as it enables a fair comparison of the take - off performance across gymnasts with varying body sizes (Bogdanis et al., 2019).

Peak power (measured in W) is a composite metric that integrates both force and velocity, providing a comprehensive measure of the explosive power exerted during take – off (Vanezis & Lees, 2005). Peak velocity (measured in $m \cdot s^{-1}$) denotes the highest speed attained during the take - off phase. This parameter is critical as it determines the fluidity of the aerial movements and the duration of the athlete's time in the air (Barker et al., 2018). The rate of force development (RFD, measured in $N \cdot s^{-1}$) quantifies the speed at which the force is generated during take - off. It is a critical determinant of the athlete's explosive strength capabilities (Mackala et al., 2013). Impulse (measured in $N \cdot s$), which accounts for the product of force and the time interval over which it acts, has a direct bearing on the stability and continuity of the jump (Cabrejas et al., 2023).

2.5.2 Flight Phase

The flight phase is characterized by the need for gymnasts to maintain a high degree of balance and coordination. This is essential for ensuring the smooth execution of aerial maneuvers and for preparing the body optimally for the subsequent landing phase. The design and execution of aerial actions play a pivotal role in guaranteeing the stability and safety of the landing (Gollhofer & Bruhn, 2003). Precise control of body orientation and movement during the flight phase can significantly influence the success of the landing.

2.5.3 Landing Phase

The landing phase demands the highest level of balance and stability from gymnasts. The magnitude and distribution of the ground reaction force during landing have a profound impact on the stability of the landing and are closely associated with the risk of potential injuries (Xiao et al., 2017). To ensure a stable landing, gymnasts must exercise precise control over their center of mass (COM) to prevent any significant deviations beyond the base of support (BOS). As pointed out by (Park et al., 2008), maintaining balance during landing is of utmost importance, and any loss of balance can lead to suboptimal landings or even injuries.

For the landing - phase testing in this study, a 10 - cm standard jump box was set up in strict accordance with the standards promulgated by the International Gymnastics Federation

(Niespodziński et al., 2021). This standardized setup allowed for a consistent and reliable evaluation of gymnasts' landing performance.

The landing process can be further dissected into three sub - stages. The deceleration stage involves the absorption of the impact forces generated upon landing through the controlled flexion of the knee and ankle joints. If the GRF is excessively large and not adequately buffered, it can lead to various joint - related injuries (McKay et al., 2001). The balance adjustment stage follows, during which the central nervous system rapidly modulates the relationship between the COM and the BOS. This process is highly dependent on the rapid activation of the quadriceps and gastrocnemius muscles, as reported by (Griffin et al., 2006). Finally, in the stabilization stage, gymnasts are required to swiftly adjust their body postures to maintain the COM within the BOS, thereby preventing falls or forward tilts. At this stage, both static and dynamic balance rely heavily on the strength of the lower - limb muscles and the athlete's proprioceptive sense (Rossignol et al., 2006).

The stability during landing can be comprehensively evaluated using a suite of metrics, including landing impact force (N), COM displacement (Holden et al., 2016), landing time (s), and postural control. These metrics can be accurately measured and analyzed through advanced techniques such as 3D motion capture and video analysis (Christoforidou et al., 2017; Cleveland, 2011; Reily et al., 2017). Additionally, the dynamic balance ability of gymnasts can be effectively assessed using methods like the 8 - point star offset test. This test is designed to evaluate an athlete's adaptability and balance control in multiple directions under dynamic conditions (Ringhof & Stein, 2018).

By integrating the performance metrics across the take - off, flight, and landing phases, a comprehensive and in - depth understanding of gymnastic jumping mechanics can be achieved. This knowledge base provides invaluable insights for optimizing training regimens, enhancing gymnastic performance, and minimizing the risk of injuries during training and competition.

Table 4 summarizes the published research the tests of jumping skills in gymnastics, the testing instruments utilized, and key outcomes.

Table 4: Summary of the jumping ability test programme

Author	Country	Population	Study design	testing time	Testing Instruments	Test content	Outcome
Feng et al., 2024	German	Artistic gymnasts N=54 Sex = Female Age: 15.4 ± 1.2 years Control group: 18 Experimental group: 18/18	RCT	Baseline Measurement End of experiment week 8 test	1. Force Plate 2. Photoelectric timing system or vertical jump test equipment 3. High-Speed Camera	1.Squat Jump (SJ) 2.Countermovement Jump (CMJ） 3.Reactive Strength Index (RSI）	1. Increased vertical jump height: Lower limb explosive strength training (e.g., squat jumps, countermovement jumps) may significantly enhance vertical jump height. 2. RSI improvement: Training targeting reactive strength (e.g., plyometric training) may enhance muscle elasticity, shorten ground contact time, and improve jump efficiency. 3. Optimized force output: Force plate data show an accelerated rate of force development, indicating improved neuromuscular coordination.
Bogdanis et al., 2019	Greece	Artistic gymnasts N=50 Sex = Female Age: EG=28.7 ± 5.8 years CG=27.5 ± 6.0 years Control group: 17 Experimental group: 33	RCT	Baseline Measurement End of experiment week 8 test	1. Force Plate 2. Photoelectric timing system or vertical jump test equipment	1. Jumping performance: Single-leg and double-leg reverse jump (CMJ) Deep squat jump (SJ) Standing long jump (SLJ) Drop jump (DJ) 2. Sprint speed: 10 meters and 20 meters straight-line sprint tests 3. Change of direction speed 3. 5+5 meters and 10+10 meters 180° turning run test	1. Enhanced jumping ability: Multi-directional jump training (e.g., standing long jump, drop jump) may improve lower limb explosive power, increasing both jump height and distance. 2. Improved sprint speed: Short-distance sprint training combined with strength exercises may shorten sprint time. 3. Optimized agility: Direction change training (e.g., 180-degree turn running) may enhance change-of-direction speed and movement coordination.
Ma et al., 2024	Polish	Artistic gymnasts N=73 Sex = Female Age: 16.2 ± 1.3 years Control group: 25 Experimental group: 24/24	RCT	Baseline Measurement End of experiment week 8 test	Force Plate	Countermovement Jump Test (CMJ): assesses vertical jumping height and lower limb explosive power.	1. Significantly increased vertical jump height: Specific training for countermovement jumps may optimize the force generation efficiency of lower limb extensor muscles. 2. Enhanced explosive strength: Force plate data show increased peak power, indicating the enhanced ability of muscles to generate greater force in a short period.

2.6 Stability capability

Stability refers to the body's ability to maintain or quickly restore balance when subjected to internal and external forces. It is generally categorized into static stability and dynamic stability, which respectively describe balance in stationary and moving states (Eleni G Fotiadou et al., 2009; Gebel et al., 2020). In gymnastics, stability is a fundamental element for athletes to perform precise movements and is closely related to their performance and safety.

Stability directly affects gymnasts' ability to execute complex skills. For example, during balance beam routines, athletes must precisely control their center of gravity (COG) to avoid falling or deviating from the intended movement trajectory (Leetun et al., 2004). Moreover, enhanced stability can effectively reduce the stress on muscles and joints, thereby decreasing the risk of injury (Promsri et al., 2021) (Ayala et al., 2024). This makes stability of crucial importance in gymnastics and other sports that require high - intensity strength output and precise coordination, serving as a key factor in improving competitive performance (McGill, 2010).

To enhance stability, gymnasts can adopt various strategies. Maintaining a stable center of gravity (COG) through awareness and targeted training, as highlighted by (Norwood et al., 2007) and (Kibler et al., 2006), is critical for improving balance and preventing deviations. Task decomposition training—breaking complex movements into simpler components—enables athletes to better master motions, enhance stability, and reduce execution difficulty (Land et al., 2013). Moreover, core - strength training focusing on key muscles like the rectus abdominis, transverse abdominis, and erector spinae offers better support and stability during challenging routines (Sternlicht et al., 2007); (de Bruin et al., 2021).

In gymnastics, stability during the jumping and landing phases is of utmost importance. Landing stability reflects the body's ability to absorb impact forces and maintain balance, with key test metrics including: Landing Impact Force (N), which measures the ground reaction force (GRF) at the moment of landing and directly demonstrates an athlete's capacity to absorb impact forces (Seegmiller & McCaw, 2003); Center of Mass Displacement, which evaluates the movement of the center of gravity (COG) during landing—the smaller the displacement, the higher the stability (Dingenen et al., 2016); Landing Time (s), which refers to the time required for the body to stabilize after touching the ground and reflects the athlete's recovery speed (Nazari & Hooi, 2019); and Postural Control, which uses 3D motion capture or video analysis techniques to assess the stability and coordination of various body parts during landing (Müller et al., 2017).

Stability testing also includes dynamic balance assessments, such as the 8 - Point Star Offset Test. This test mainly evaluates the athlete's dynamic balance and adaptability in multiple directions, especially in complex and multi - task environments (Yoon et al., 2020). By incorporating these metrics into the stability assessment system, a comprehensive and in - depth analysis of gymnasts' performance can be achieved, providing valuable references for improving execution accuracy, reducing the risk of injury, and optimizing training programs (Daly et al., 2001).

It is worth noting that according to the Dynamic Systems Theory (Flam & Powell, 2009), the stability of gymnastic landings is essentially a self-organizing process of movement coordination patterns. When the center of mass (COM) deviation exceeds the critical threshold (usually 15% - 20% of the projected area of the base of support, BOS), the human system will be adjusted through a series of cascade reactions of ankle - hip - stepping strategies (Williams et al., 2016). Beginner athletes often experience regulatory failures due to neuromuscular delays (an average of 180–220 milliseconds), which well explains why their landing error rate is 3.2 times higher than that of elite athletes (Wesley et al., 2015). This theory further reveals the complex mechanisms behind the stability of gymnastic landings and is interrelated with the previously mentioned stability strategies and testing metrics. For example, when conducting center-of-gravity control training, athletes can, based on the Dynamic Systems Theory, be clearer about how to reasonably adjust their body movements upon landing to avoid the COM deviation exceeding the critical threshold, thereby improving landing stability. Coaches can also refer to this theory when designing task-decomposition training. In view of the neuromuscular delay problem of beginner athletes, they can develop more targeted training steps to gradually improve the athletes' self-adjustment ability during landing (Gittoes & Irwin, 2012).

Table 5 summarizes the published research the tests related to stability in gymnastics, the testing instruments employed, and key outcomes.

Table 5: Summary of the stability test programme

Author	Country	Population	Study design	Testing time	Testing Instruments	Test content	Outcome
Ma et al., 2024	China	Artistic gymnasts N=40 Sex = Female/male: No details on the exact quantity Age: 16-18 years Control group: 20 Experimental group: 20	RCT	Baseline Measurement End of experiment week 12 test	Electromyography (EMG)	1.Superman Test 2.Plank Test 3.Crunch Test 4.Side Plank Test 5.Leg Raise Test 6.Single-Leg Balance Test 7.Static Squat Test 8.Bird-Dog Test	1. Enhanced core activation: Training improves the coordination and endurance of core muscles (e.g., transverse abdominis, multifidus), enhancing spinal stability. 2. Increased static endurance: Longer duration in plank and side plank exercises indicates improved anti-fatigue capacity. 3. Optimized dynamic control: Reduced body sway during single-leg balance and bird-dog tests reflects improved neuromuscular control.
Hao et al., 2022	China	Artistic gymnasts N=30 Sex = Female Age: EG=20.5±1.5 years CG=21.5±1.5 years Control group: 15 Experimental group: 15	RCT	Baseline Measurement End of experiment week 8 test	Star Excursion Balance Test	1. Rotating sit-ups 2. Push-ups 3. Seated Pull Down 4. Kick 8 Point Star Offset	1. Enhanced balance ability: Increased reach distance in the star balance test indicates improved lower limb flexibility and dynamic balance. 2. Increased muscle strength: More repetitions/higher resistance in push-ups and seated cable rows reflect stronger upper limb and back muscles. 3. Optimized coordination: Improved efficiency in rotational sit-ups and leg kicks, with fewer compensatory movements.
Cabrejas et al., 2022	Spanish	Artistic gymnasts N=45 Sex=Female Age：10.5 ± 1.8 years Control group：22 Experimental group：23	RCT	Baseline Measurement End of experiment week 8 test	Pressure Biofeedback Unit (PBU）	1. Bent Knee Fall Out (BKFO） 2. Active Straight Leg Raise (ASLR） Pelvic Tilt Test	1. Improved pelvic stability: Reduced pelvic asymmetry in BKFO test indicates enhanced control of hip surrounding muscles. 2. Increased lower limb flexibility: Larger straight leg raise angle in ASLR test reflects improved hamstring and lumbopelvic flexibility. 3. Enhanced core anti-disturbance ability: Reduced trunk sway in cobblestone tilt test shows stronger core stability under dynamic perturbations.

2.7 Gymnastics Performance Movements

Gymnastics performance movements are a composite skill system composed of dynamic and static elements, which assess athletes' comprehensive physical qualities through specific biomechanical mechanisms, including strength, flexibility, coordination, balance, and movement accuracy. According to the apparatus classification system of the International Gymnastics Federation (de Gymnastique, 2016), these movements can be systematically divided into four major technical categories: jumping, turning, balancing, and transitional movements. Each technical module exhibits differentiated performance characteristics in apparatus such as the balance beam, floor exercise, vault, and uneven bars.

2.7.1 Jumping Movements

As the dynamic foundation of the gymnastics movement system, jumping techniques include typical modes such as jump turns, tucked jumps, split jumps, and straddle jumps. Their biomechanical characteristics can be analyzed through a three - phase model:

1. Take - off Phase: The vertical ground reaction force (GRF) is generated through the eccentric - concentric contraction coupling mechanism of the lower limb muscles. The competitive performance in this phase mainly depends on the peak force and power output efficiency, with the plantar - flexion speed of the ankle joint and the extension angular acceleration of the hip joint being the key dynamic parameters (Bath & Wang, 2024).
2. Flight Phase: Athletes need to perform multi - axial compound movements in an unsupported state. The quality of movement completion in this phase can be quantitatively assessed through the stability of the center - of - mass parabolic trajectory, the degree of conservation of angular momentum, and the two ability regulate the moment of inertia (Adashevskiy et al., 2014).
3. Landing Phase: As a key phase for injury prevention and referee scoring, the technical characteristics of this phase are reflected in the impact force attenuation, the trunk stability angle (≤5°), and the displacement of the center of pressure on the foot - apparatus contact surface (Straker et al., 2022).

2.7.2 Turning Movements

Representative turning movements, such as single - foot standing 360° turns and straight - body jump 360° turns, have their technical core in the dynamic regulation of human moment of inertia and angular velocity, which are mainly influenced by the following three elements:

1. Angular Momentum Generation: The initial rotational kinetic energy is determined by the angular impulse ($\tau\Delta t$) generated by asymmetric arm swinging in the pre - swing phase and the torque output efficiency of the supporting leg (Willson et al., 2005).
2. Posture Compensation Control: The "axial - limb" coordinated regulation strategy is adopted to maintain the stability of the rotation axis through the spatial conjugate movement of the head - shoulder - hip. The displacement of the center of pressure of the supporting foot within the base of support (BOS) should be controlled within ±2cm (Cholewicki et al., 1999).
3. Core Stiffness Regulation: The coordinated activation of the transverse abdominis and multifidus muscles forms a rigid trunk pillar, and the coupling of the momentum of the upper and lower limbs is realized through the transmission of fascial tension. The level of electromyographic activation is significantly positively correlated with the number of turns ($r = 0.72$) (Leetun et al., 2004).

2.7.3 Biomechanics and Training Optimization

The training intervention system based on movement analysis should include the following three progressive dimensions:
1. Strength Development Module: Velocity - based training (VBT) is used to enhance eccentric strength reserves, and combined training (depth jumps + turns) is used to simultaneously improve vertical jump power (≥45 W/kg) and rotational explosive power.
2. Neural Adaptation Training: The virtual reality balance training system (VRBT) is used to enhance the integration of vestibular - proprioceptive abilities, reducing the posture sway index (SI) by 30% - 40% under dynamically unstable conditions (E. D. Barrio et al., 2022).
3. Technical Diagnosis System: Inertial measurement units (IMU) and three - dimensional force platform data are integrated to establish a movement quality evaluation model containing 13 joint angle parameters and 8 dynamic indicators, achieving real - time feedback of the energy transfer efficiency of the kinetic chain (Fang et al., 2023).

2.8 Summary

In recent years, the field of balance research has witnessed remarkable advancements. Extensive studies have delved into the mechanisms underlying static and dynamic balance, as well as the corresponding evaluation methods. For instance, (Lee & Lee, 2017) conducted a longitudinal study on middle - aged and older adults, revealing that regular balance training can remarkably enhance gait stability and lower limb muscle strength. This research provides solid evidence for the positive impact of balance training on physical function maintenance in this age group (Eltoukhy et al., 2017).

Despite these significant achievements, the research on jumping ability and stability in gymnastics still has several limitations. Jumping ability and stability are fundamental to high - quality gymnastic performances. Jumping ability determines the height and smoothness of aerial maneuvers, while stability ensures accurate landings after complex movements. Current research in this area predominantly focuses on elite gymnasts. For example, the study by Sands et al., (2003) on gymnastic jumps mainly analyzed the biomechanics of top - tier athletes, overlooking the unique requirements of beginner gymnasts. There is a dearth of systematic research that combines static and dynamic balance training to enhance the jumping ability and stability of beginner gymnasts. Additionally, existing studies have not fully explored the balance control mechanisms in multi - task environments, which are common in gymnastics training. For example, gymnasts often need to perform multiple movements simultaneously while maintaining balance, but the underlying neural and biomechanical mechanisms remain unclear.

Research on individual differences in gymnastics also has room for improvement. Gender, age, and skill level can all significantly affect how gymnasts respond to balance training. For example, a study by (Milosis & Satras, 2023) indicated that male and female gymnasts may have different optimal training intensities due to physiological differences. However, these factors are not yet well - understood, and the current training methods lack generalizability and specificity, which restricts the improvement of jumping ability and stability across different groups of gymnasts.

Looking ahead, several emerging areas in the field of balance and gymnastic performance research show great promise. First, the integration of virtual reality (VR) and biofeedback in training is a burgeoning area. (Kumar et al., 2017) explored the use of the Hololens 2 for real - time center - of - mass (COM) projection training. This technology allows gymnasts to visualize their COM in real - time during training, providing immediate feedback to improve balance control. Second, the influence of gene polymorphisms, such as the BDNF Val66Met polymorphism, on the sensitivity to balance training is an area that requires further exploration. A study by (Nascimento et al., 2015) suggested that genetic factors may play a role in an individual's response to balance training, but more research is needed to fully understand these relationships. Third, the use of transcranial direct - current stimulation (tDCS) to promote vestibular cortex plasticity has also attracted attention. According to a recent study by (Kang et al., 2016), tDCS may enhance the brain's ability to adapt to balance - related training, but the optimal stimulation parameters and long - term effects remain to be determined.

The present study aims to fill the existing research gaps. It intends to systematically design a comprehensive training program that combines static and dynamic balance training, specifically tailored to beginner gymnasts. By integrating multi-task environments to simulate complex gymnastic scenarios and developing personalized training plans that consider factors such as gender, age, and skill level, this study aims to effectively improve the balance abilities and overall performance of beginner gymnasts. Long-term follow-up evaluations will be conducted to provide data-driven evidence for the effectiveness of the training. This research not only contributes to enhancing gymnastic skills but also provides valuable scientific references for injury prevention and ensuring the long - term safety of gymnasts.

CHAPTER 3

3.0 METHODOLOGY

3.1 CONCEPTUAL FRAMEWORK

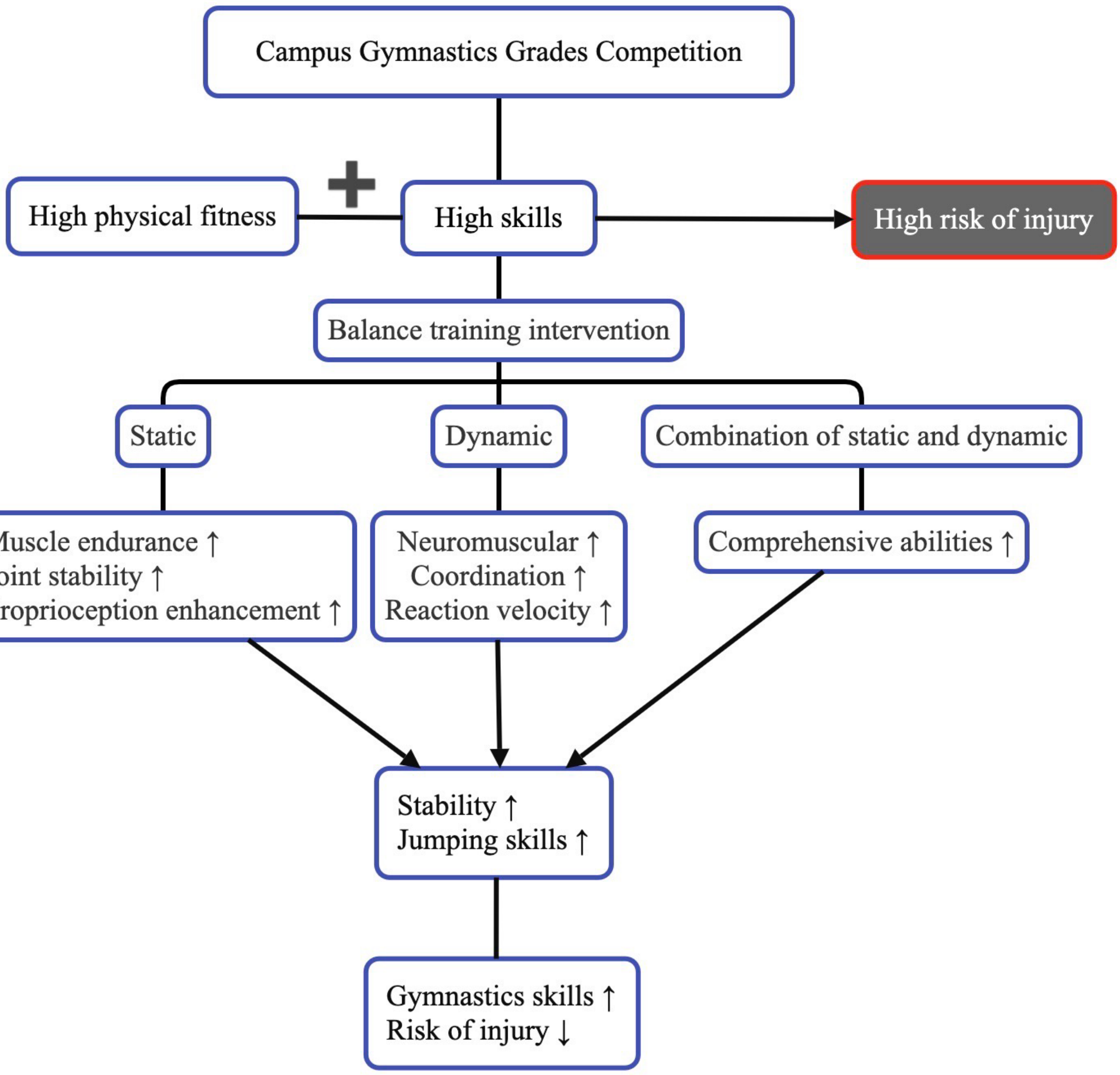


Figure 1 Conceptual Framework

3.2 Research design

This study employs a four-arm parallel-group randomized controlled trial design to evaluate the efficacy of static, dynamic, and combined balance training on beginner gymnasts' stability and rotational performance. Figure 2 illustrates the experimental flow, including recruitment, randomization, interventions, and outcome assessments.

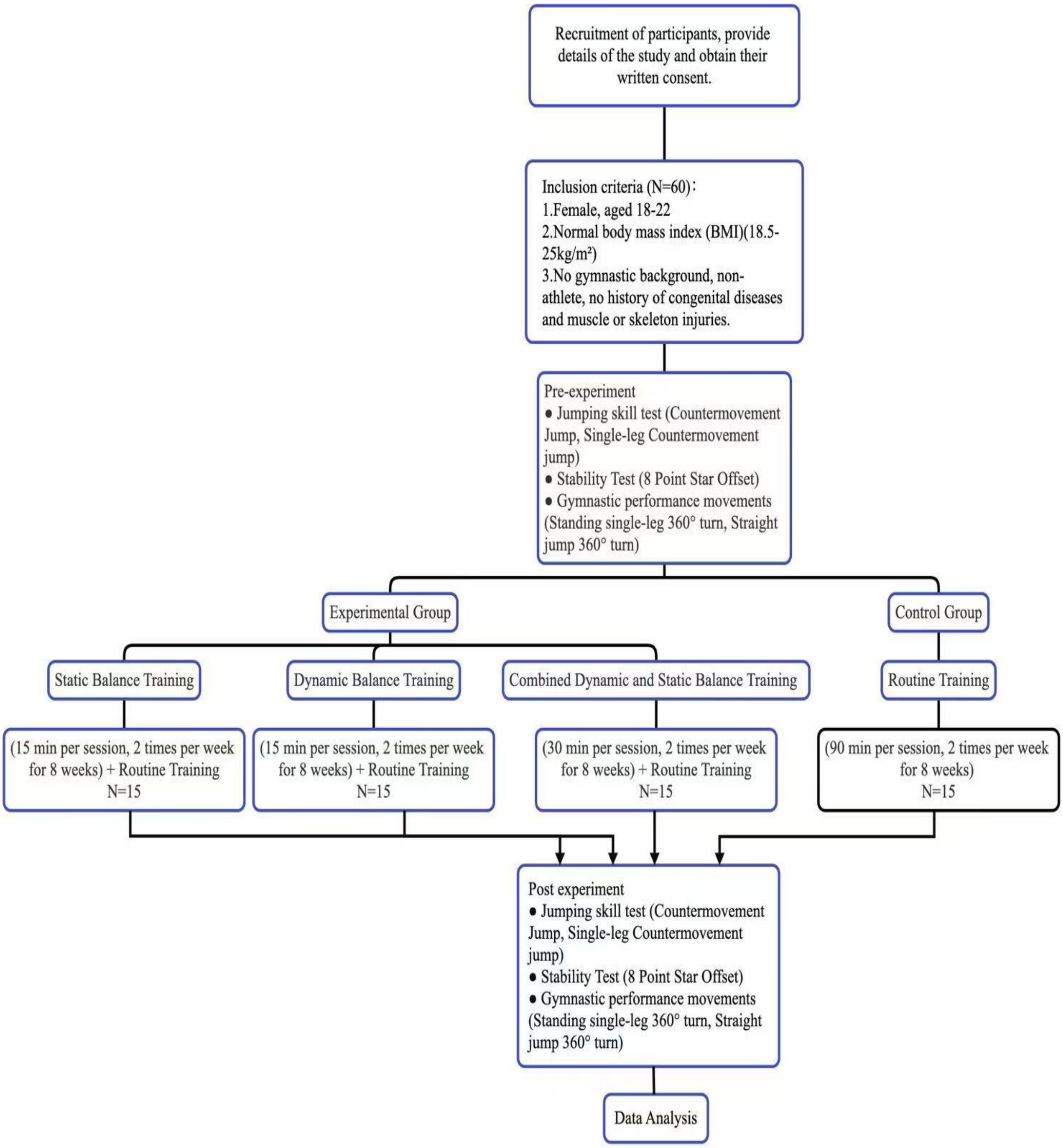


Figure 2 Flow chart of the experimental design

3.2.1 Study design

3.2.1.1 History of Beijing Sport University Campus Competition Results

This research design is based on the training designs in 2021, 2023, and 2024 by Coach Li Ji from Beijing Sport University. This training plan is unpublished.

Rationale for this training plan:

The campus gymnastics proficiency competition of Beijing Sport University can be traced back to 2019. In the early years of the competition (before 2021), due to low awareness and insufficient promotion, only a very small number of students participated. In recent years, with the increasingly severe employment situation in China, this competition has become an important opportunity for students specializing in gymnastics to obtain gymnastics level certificates.

The statistics given by Coach Li Ji show that since 2021 (the competition was suspended in 2022 due to the pandemic), students instructed by Coach Li Ji have achieved results reaching the national second-level athlete standard in three consecutive competitions in 2023 and 2024. In addition, the research team has collected, for the first time, Coach Li Ji's unpublished training plans, aiming to provide theoretical and practical references for subsequent students participating in campus gymnastics competitions.

Table 6 lists the results of Li Ji's students from Beijing Sport University in the Competitive Gymnastics Campus Grading Competition during 2021, 2023, and 2024. The training methods he employed are illustrated in Tables 7 and 8; accordingly, these methods will be implemented in the routine training of the control group.

Table 6: History of Results for Beijing Sport University Campus Gymnastics Competitions (2021, 2023, 2024)

	Name	Vault	Rank	Uneven Bars	Rank	Balance Beam	Rank	Floor Exercise	Rank	All-Around Individual	Rank
Women's Level 2 (Graduate Group) in 2021	Yu, J. M	8.45	5	2.65	9	8.90	1	9.25	1	26.60	1
	Chen, J. L	8.65	2	2.85	8	8.85	2	8.90	4	26.40	2
	Liang, S. Y.	8.9	1	8.40	3	7.60	8	8.30	6	25.60	4
	Chai, H. W	8.65	2	1.30	10	7.80	6	9.05	2	25.50	5
	He, Z. Y.	8.25	8	8.30	5	8.10	5	8.10	8	24.65	9
	Fan, S. S.	8.45	5	8.40	3	7.50	9	7.65	10	24.50	10
Women's Level 2 (Graduate Group) in 2023	Lei, L. Z.	9.0	5	8.70	4	9.30	1	8.45	4	27.0	1
	Wang, A. Z	9.10	2	8.75	2	8.50	5	8.35	8	26.35	2
	Duan, W. C.	8.95	7	8.80	1	8.35	8	8.40	7	26.15	6
	Yang, L.	8.25	11	7.95	8	8.25	9	8.50	2	25.0	10
Women's Level 2 (Graduate Group) in 2024	Gao, N. F.	9.20	1	8.75	3	8.30	3	8.40	9	26.35	1
	Liu, Y. J.	8.30	7	9.20	1	7.65	5	8.60	5	26.10	2
	Liu, Y.	8.80	2	8.25	7	4.60	10	8.45	8	25.50	7
	Yang, Y. P.	8.40	5	8.60	5	7.80	4	8.20	11	25.20	9

*Note:

1. The criteria for second-level athletes are: achieving the top 2 places in individual gymnastics events and scoring at least 25 points in personal performance for female athletes (3 out of 4 events can be selected) to qualify for grading.
2. The all-around individual score is calculated by selecting the top three highest scores from four events.

Table 7: Routine exercise- Training Plan

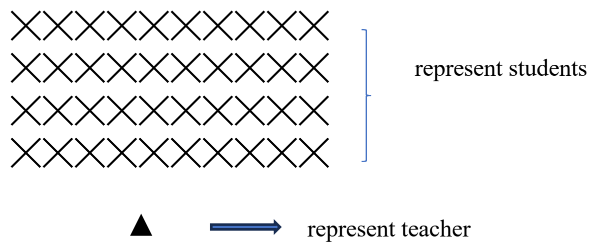
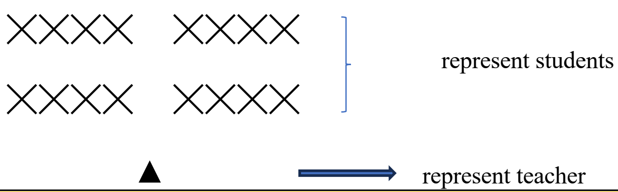
Teaching Process	Time	HR	Teaching Content	Intensity	Organization, Methods, and Requirements
Introduction section	3 min	80 ↓ 120	1.The class monitor organizes the lineup and reports attendance. 2.Greetings between teacher and students. 3.Announce the objectives of the preparation section for this lesson: (1) Learn to transform a single horizontal row into two horizontal rows in place and revert to the original formation. (2) Practice bodyweight gymnastics exercises. 4.Arrange tasks for the observer(s).		Organization: Assemble in four horizontal rows 
Preparation section	40 min		Routine Drills: 1.At Ease, Attention, Align, and Counting Off. 2.Transform a single horizontal row into two horizontal rows in place. 3.Transform two horizontal rows back into a single horizontal row. Bodyweight Exercises: Learn raising, bending, swinging movements, and simple movement combinations: 1.Side raise, overhead raise, forward raise, side-up raise, side-down raise, forward-up raise, forward-down raise. 2.Arm side bend and arm swing.	2-3 times	Organization: Combined class for collective practice Organizational Teaching Methods: 1.Teacher demonstration. 2.Explanation of movement requirements and command essentials (including characteristics of preparatory commands and execution commands). 3.Teacher-led practice: The teacher leads students in practicing command execution. 4.Group-based student practice: Students are divided into small groups for hands-on practice, with teachers providing guidance to each group individually. 
Rest for 5 minutes					

Table 7: Routine exercise- Training Plan (continued)

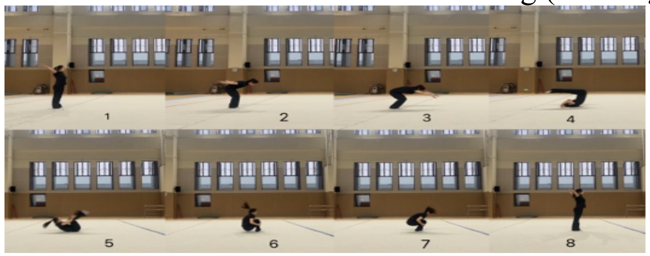
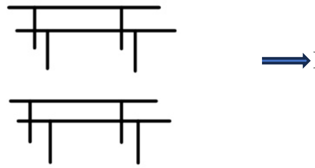
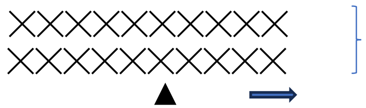
Teaching Process	Time	HR	Teaching Content	Intensity	Organization, Methods, and Requirements
Main section	40 min	80 ↓ 12 0	Main Section I. Special Preparatory Activities Specific warm-up exercises to prepare for the main techniques. II. Techniques 1.Tucked Forward and Backward Rolling (Rocking Motion)  Key Points of Forward Roll 1. Stand with hands extended horizontally to the sides. 2. Swing hands backward while squatting with knees bent. 3. Extend hands forward. 4. Place hands on the ground, lower your head, and push off with your legs to roll forward. 5. Round your back and push with your hands. 6. Hug your knees with both hands. 7. Hug your knees, tuck your body, and smoothly transition into a squatting - standing position. 8. Return to a standing position with hands extended horizontally to the sides, head up, and chest out. III. Parallel Bars	2-3 times	II. Groups of 2-3 people. (Techniques)  III. Students are divided into two groups to practice simultaneously on two different apparatuses. (Parallel Bars) 
Closing section	2 min		1.Return the equipment to its proper place. 2.Relaxation activities (approximately 1 minute). 3.Summary of the lesson.		Assemble in two horizontal rows. 

Table 8: Routine exercise- Training Plan

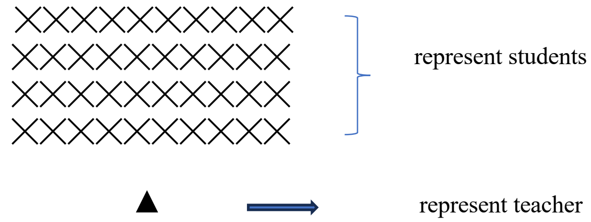
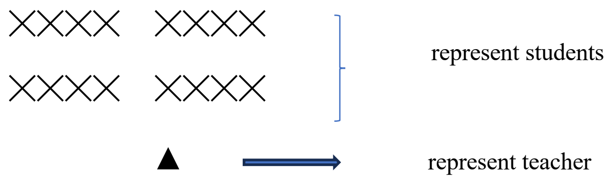
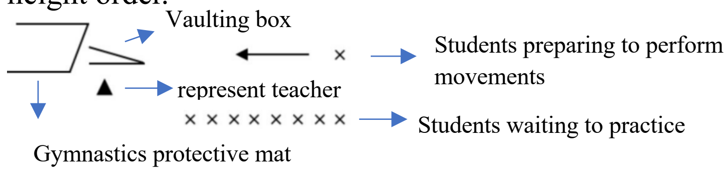
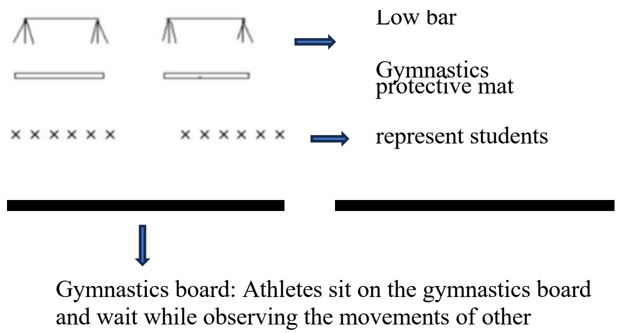
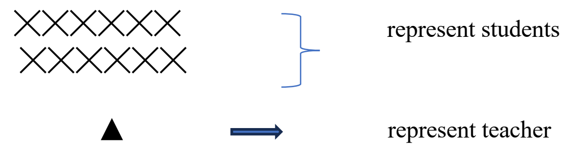
Teaching Process	Time	HR	Teaching Content	Intensity	Organization, Methods, and Requirements
Introduction section	3 min	80 ↓ 120	1.The class monitor organizes the lineup and reports attendance. 2.Greetings between teacher and students. 3.Announce the objectives of the preparation section for this lesson: 4.Learn stationary formation drills: transforming one row into three rows and reverting to the original formation. 5.Learn/review bodyweight gymnastics movements. 6.Assign tasks for observers.		Organization: Assemble in four horizontal rows 
Preparation section	40 min		I. Games 1.Number-calling relay game II. Formation Drills 1.Transform a single horizontal row into three horizontal rows in place. 2.Transform three horizontal rows back into a single horizontal row in place. III. Bodyweight Exercises 1.Review the movements learned in the previous lesson. 2.Upper body movements: Arm circles and rotations. 3.Lower body movements: Half squats and full squats.	2-3 times	Organization: Combined class for collective practice Organizational Teaching Methods: 1.Teacher demonstration. 2.Explanation of movement requirements and command essentials (including characteristics of preparatory commands and execution commands). 3.Teacher-led practice: The teacher leads students in practicing command execution. 4.Group-based student practice: Students are divided into small groups for hands-on practice, with teachers providing guidance to each group individually. 
Rest for 5 minutes					

Table 8: Routine exercise- Training Plan (continued)

Teaching Process	Time	HR	Teaching Content	Intensity	Organization, Methods, and Requirements
Main section	40 min	100 ↓ 140	I. Special Preparatory Activities • Specific warm-up exercises to prepare for the following techniques. II. Jumping Techniques • Learn run-up and take-off using a springboard. III. Low bar practice • Learn to jump onto the bar to achieve a support position and perform a forward roll dismount.	2-3 times	Organization: Practice complete movements in turn according to height order.  Organization: Students are divided into two groups for practice. 
Closing section	2 min		1.Return the equipment to its proper place. 2.Relaxation activities (approximately 1 minute). 3.Summary of the lesson.		Assemble in two horizontal rows. 

3.2.1.2 Tests and Training Plan Schedule for the Experimental Group

The test protocols and training components for stability and jumping skills were derived from outcome measures in an unpublished systematic review and deemed appropriate following discussions with Li Ji, a gymnastics coach at Beijing Sport University. Thus, Table 9 and 10 present the stability and jumping test programme to be conducted, table 11 outlines the 8-week training schedule for the experimental group participants.

Table 9: Stability and Jumping Test Programme

Test items	Testing time	Testing content	Testing Instruments
Stability test	Baseline Measurement End of experiment week 8 test	8 Point Star Offset	Star Excursion Balance Test
Jumping test	Baseline Measurement End of experiment week 8 test	1. Countermovement Jump 2. Single-leg countermovement Jump	Force Plate

Table 10: Gymnastic Performance Movements

Test items	Testing time	Testing content	Testing Instruments
Standing Single-leg 360 ° turn	Baseline Measurement End of experiment week 8 test	Standing Single-leg 360 ° turn	3D motion capture technology
Straight jump 360 ° turn	Baseline Measurement End of experiment week 8 test	Straight jump 360 ° turn	3D motion capture technology

Table 11: Experimental Training group

Training Programme	Routine Training	Group1 (Static balance training)	Group2 (Dynamic balance training)	Group3 (Static and Dynamic balance training)
Week 1				
baseline test				
Week 2-3				
	Basic Adaptation Period			
●Activity/Mode	①Preparatory Exercises ②Review of the Complex Movements from the Previous Session ③Practice of New Complex Movements ④Strength Training ⑤Relaxation Exercises	①Double leg stand on a BOSU ball ②Single leg stand on a BOSU ball	①Jump in multiple directions on one leg ② Half squat exercise	①Single-leg stance+ Leg - lifting exercise ②Half squat exercise + Throwing - catching ball exercise
●Duration	● 90 minutes/per session	●15 minutes/ session	●15 minutes/ session	●30 minutes/ session
●Intensity (Heart rate)	● 100bpm-160bpm	● 80bpm-100bpm	● 90bpm-110bpm	● 90bpm-110bpm
●Inter-group Rest Duration	● 2 minutes	● 2 minutes	● 2 minutes	● 2 minutes
Week 4				
	Ability Strengthening Period			
●Activity/Mode	The same content	①Eyes-closed double-leg stance ②Plank support	①Jumping onto a low balance beam ②Half squat exercise	①Jumping onto a low balance beam + Walking on the Balance Beam + Landing control training ②Half Squat Exercise + Throwing - catching ball exercise
●Duration	● 90 minutes/per session	●15 minutes/ session	●15 minutes/ session	●30 minutes/ session
●Intensity (Heart rate)	● 100bpm-160bpm	● 80bpm-110bpm	● 90bpm-110bpm	● 90bpm-110bpm
●Inter-group Rest Duration	● 2 minutes	● 2 minutes	● 2 minutes	● 2 minutes
Week 5				
	Ability Strengthening Period			
●Activity/Mode	The same content	①Eyes-closed Single-leg stance ②Half Squat Exercise	①Jumping onto BOSU ball ② Half squat-to-stand and catch-and-throw ball exercise	①Jumping onto BOSU ball + Double-leg stance ②Plank and convert to two-hand support
●Duration	● 90 minutes/per session	●15 minutes/session	●15 minutes/session	●30 minutes/session
●Intensity (Heart rate)	● 100bpm-160bpm	● 80bpm-110bpm	● 90bpm-120bpm	● 90bpm-120bpm
●Inter-group Rest Duration	● 2 minutes	● 2 minutes	● 2 minutes	● 2 minutes
Week 6				
	Ability Strengthening Period			
●Activity/Mode	The same content	①Jumping onto BOSU ball + Eyes-closed double-leg stance ②Single-Leg Standing Leg + Leg Lift Exercise	①Practice of jumping with rotation ②Plank and convert to two-hand support	①Jump training + Jumping with rotation ②Plank and convert to two-hand support + Plank support
●Duration	● 90 minutes/per session	●15 minutes/ session	●15 minutes/session	●30 minutes/session
●Intensity (Heart rate)	● 100bpm-160bpm	● 80bpm-120bpm	● 90bpm-120bpm	● 90bpm-120bpm
●Inter-group Rest Duration	● 2 minutes	● 2 minutes	● 2 minutes	● 2 minutes
Week 7				
	Integration and Optimization Period			
●Activity/Mode	The same content	①Single-Leg Standing Leg + Leg Lift Exercise ②Single-Leg Standing Pointe Exercise	①Walking on the Balance Beam ②Landing control training	①Jumping onto a low balance beam + Walking on the Balance Beam + Landing control training ②Forward roll + swallow balance
●Duration	● 90 minutes/per session	●15 minutes/session	●15 minutes/session	●30 minutes/session
●Intensity (Heart rate)	● 100bpm-160bpm	● 80bpm-120bpm	● 90bpm-120bpm	● 90bpm-120bpm
●Inter-group Rest Duration	● 2 minutes	● 2 minutes	● 2 minutes	● 2 minutes
Week 8				
Post test				

3.2.1.3 Decomposition and Description of Training Movements

As shown in Figure 3a-o, the following are the training movements. The participants, personally guided by Coach Li Ji from Beijing Sport University, will complete these movements under his supervision. During the recording process, Coach Li will monitor the details of the movements throughout and carry out professional optimizations to ensure their standardization. All motion imagery materials will not reveal the identities of the participants.

		
Stand on the hemispherical surface center of a BOSU ball with both legs, maintaining continuous core engagement. Place palms inward on thighs and adjust eye opening as needed to sustain balance and postural stability.	Stand on the hemispherical center of a BOSU ball with the dominant leg, positioning the non-dominant leg in a passé (toes touching inner knee). Maintain core engagement and hold hands in lateral horizontal abduction or resting on thighs.	Initiate single-leg stance on the BOSU ball's hemispherical surface. Following dominant leg stabilization, engage the core to lift the non-dominant leg anteriorly, grasp the ankle with the contralateral hand, and maintain the ipsilateral hand in lateral horizontal abduction.
Figure 3a Double leg stand on a BOSU ball	Figure 3b Single leg stand on a BOSU ball	Figure 3c Leg Lift Exercise

Front view	Side view
	

Stand in front of the balance beam and maintain a single-leg stance with the dominant foot. Use one or both hands to grip the beam for balance. Lift the other leg into a passe position (ballet term), where the toes gently touch the inner side of the knee. Rise onto the balls of the feet (toes fully pointed) with the standing leg. Each set consists of 10 repetitions of rising (plantarflexion) and lowering (dorsiflexion) the heel, followed by a 10-second hold in the toe-standing position, completing 3 sets in total.

Figure 3d Single-Leg Standing Pointe Exercise

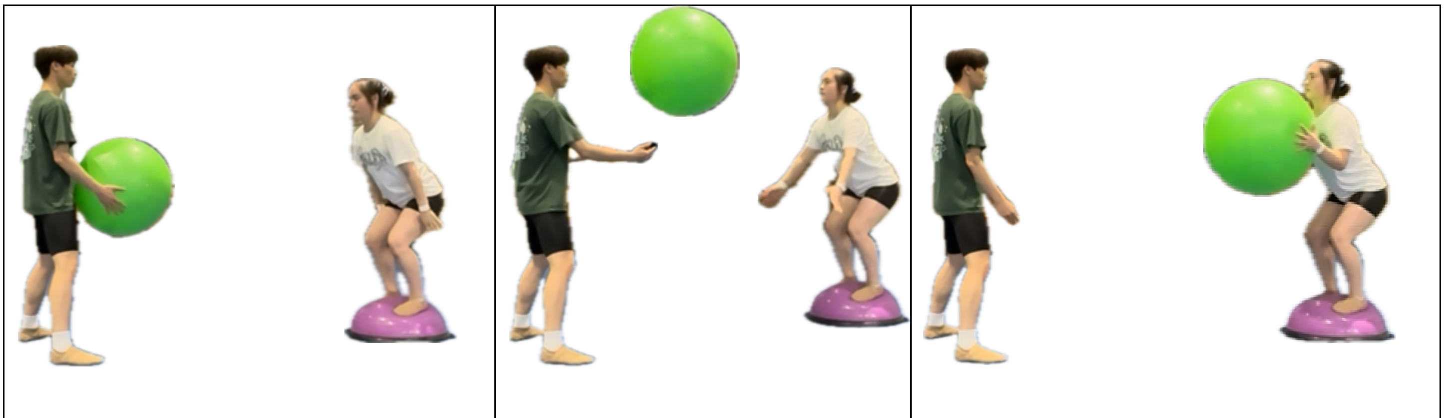
Front view			Side view		
					

① Stand with your feet shoulder-width apart, toes slightly outward at about 15°.
② Shift weight posteriorly, initiate squatting at hip axis with neutral spine and engaged core. Align knees with second toes (avoid anterior translation beyond toes) until thighs reach horizontal plane. Concurrently, flex elbows to position fists at chest level, with fingertips opposed and elbows slightly abducted; maintain forward gaze for postural stability.
③ Activate quadriceps and gluteus maximus, extend knees and hips in coordination while pushing through heels. Sustain core engagement and forward visual focus, returning to full upright stance.

Figure 3e Half Squat Exercise

① Stand facing the hemispherical side of a BOSU ball with both feet, perform shoulder abduction to 90 degrees, and maintain core engagement.
② Maintain shoulder abduction at 90°, execute a quarter squat, engage the glutes and quadriceps to generate elastic energy, and prepare for vertical propulsion.
③ Explosively execute a vertical leap, swinging the hands forward to shoulder height. Maintain a rigid straight-body position from head to heels, fix your gaze on the BOSU ball's hemispherical surface, and sustain core tension until landing.

Figure 3f Jumping onto BOSU ball (Step-by-Step Breakdown)



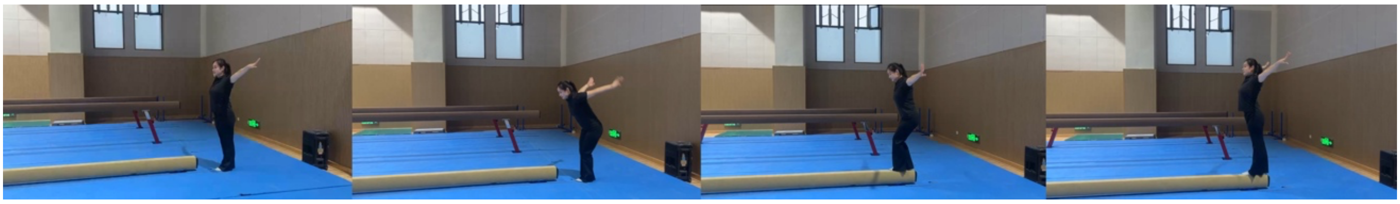
① Stand on the hemisphere. Hinge at hips, lower to 45° squat. Knees over toes, core tight, eyes forward.	② Watch the ball, extend arms to catch. Bend elbows to absorb impact, pull ball back to chest, steady your squat.	③ Use core twist or arm swing to toss the ball up (chest height). Control the arc for easy catches.

Figure 3g Half squat exercise + Throwing - catching ball exercise

Front view	Side view

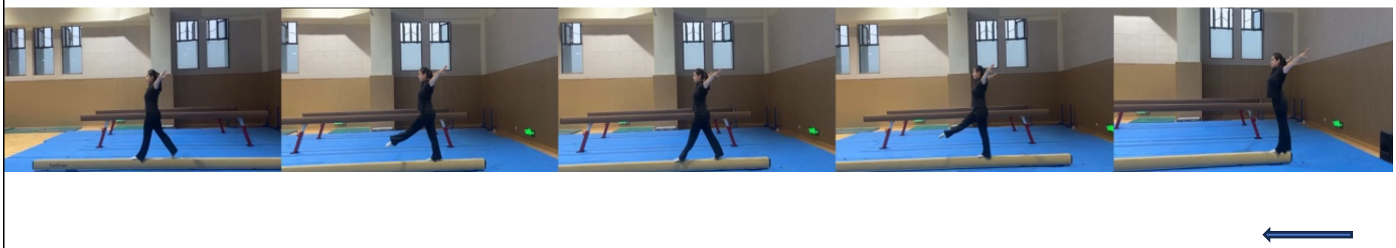
① Elbows flexed at 90°, forearms on ground (palms down), elbows under shoulders; toes planted, heels extended. Maintain a straight line from head to heels with neutral spine. Activate core muscles and depress scapulae.
② Initiate with dominant hand: advance palm forward, fingers spread, extend elbow (control shoulder movement). Shift weight to opposite forearm for balance. Repeat with non-dominant hand to achieve shoulder-width placement, fully extending arms with slight elbow flexion. Maintain trunk stability and visual focus on the ground.
③ Hands shoulder-width apart, fingers forward, arms vertical under shoulders. Sustain straight-body alignment and core engagement with neutral hip/trunk rotation.

Figure 3h Plank and convert to two-hand support + Plank support



Participants adopt a feet-together upright stance facing the beam, arms at sides. Initiate by shifting center of mass posteriorly to heels, flexing knees to store energy, and swinging arms backward. Coordinate lower limb push-off (ankle plantarflexion, knee extension) with forward-upward arm swings for takeoff. Maintain moderate trunk anterior tilt and upright alignment during flight, fixating visually on the landing spot. Land with simultaneous full-foot contact, dorsiflex ankles and flex knees to cushion impact, while abducting arms to 90° for stability. Post-landing, activate core/limbs and use visual-proprioceptive feedback to stabilize center of mass on the beam.

Figure 3i Jumping onto a low balance beam (low balance beam)



The lead leg flexes at the hip joint to a certain degree and slightly flexes the knee to swing forward, with the heel landing on the beam's midline. Subsequently, the body's center of mass shifts to the lead leg as the trailing leg lifts off the beam, and the ankle appropriately dorsiflexes to ensure toe clearance during the swing phase. Subsequent steps maintain a heel-to-toe progression where each foot lands directly in front of the previous one, with the single-leg stance phase accounting for a large proportion of the gait cycle, minimizing lateral displacement of the center of mass.

Figure 3j Walking on the Balance Beam (low balance beam)

Standing upright at the low beam's end, swing arms back to jump, keeping the body upright in the air. Land with forefeet first, then fully cushion with feet, using sight and body awareness to steady the center of mass on the ground, completing the beam-to-ground transition.

Figure 3k Landing control training (low balance beam)

Stand upright at the high beam's end, swing arms back to jump, keeping the body upright or slightly leaning forward mid-air. Land on forefeet first, then bend knees and ankles deeply to cushion the impact, swinging arms forward to steady balance. Use eyes and body awareness to settle the center of mass safely on both feet, completing the beam-to-ground dismount.

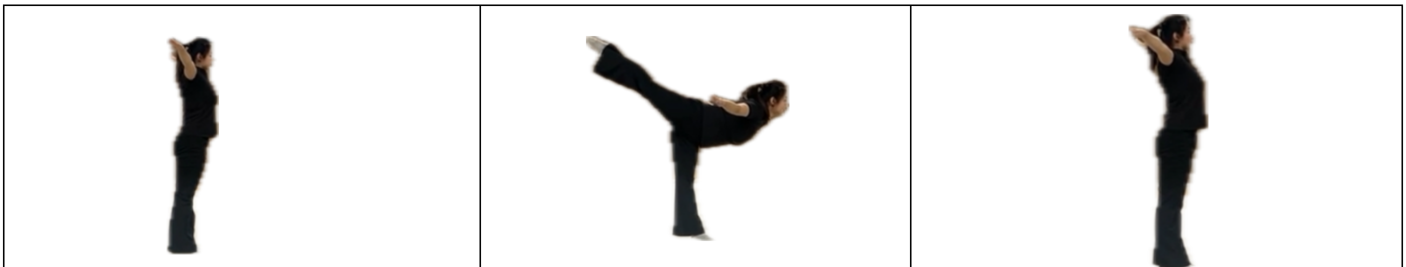
Figure 3l Landing control training (high balance beam)

Stand with your feet shoulder-width apart, lean your body slightly forward, and bend your knees into a half-squat position (ensure your knees do not go past your toes and your hips are pushed back), while engaging your core muscles to maintain stability. Then, explosively push through your feet and use coordinated arm swings to jump upward as high as possible. When landing, gently absorb the impact by bending your knees and smoothly returning to the half-squat position to keep your body balanced. Training recommendation: Perform 10 repetitions per set, and complete 3 sets in total.

Figure 3m Jump training

The subject assumes an upright posture (with the body stiff and straight like a "straight stick", core engaged, and no torso bending), pushes off with one or both feet to jump, completes a 360-degree horizontal rotation in the air around the body's longitudinal axis, while keeping the body fully extended and limbs fixed (such as arms pressed tightly against the torso or maintaining a specific pose), and finally lands smoothly on both feet, with the body still maintaining upright stability upon landing.

Figure 3n Jumping with rotation



Stand on one foot, extend and lift the other leg straight backward and upward (with toes pointed), lean the upper body forward until it is parallel to the ground or lower, and naturally spread the arms (such as in lateral or forward raises) to maintain balance. It requires the standing leg to stay straight and stable, the lifted leg and upper body to form a straight line, the core to be engaged, and the eyes to look forward or at the ground, demonstrating flexibility and balance.

Figure 3o Swallow balance

3.2.2 Testing Components

When evaluating the effectiveness of balance training for athletes, the Star Excursion Balance Test (SEBT) and the force plate, which are used for the 8 - Point Star Offset Test, Countermovement Jump (CMJ), and Single - Leg Countermovement Jump (SLCMJ), play a crucial role in assessing athletes' stability.

3.2.2.1 8 - Point Star Offset Test (using SEBT)

Participants stand on one leg at the center of a star-shaped testing platform, extend the non-supporting leg slowly toward eight predefined directions (forward, backward, lateral, and four diagonal directions), and touch the farthest marked point on the ground with the toe precisely before returning to the starting position at a constant speed (Gribble et al., 2012). Throughout the test, the trunk must remain vertically stable, the knee of the supporting leg bent at approximately 20°, hip tilting or center of gravity displacement avoided, and the arms either hanging naturally or fixed at the waist to maintain balance (Bastien et al., 2014). If the supporting foot moves, the non-supporting leg touches the ground accidentally, or the body loses control and interrupts the movement, the trial is deemed invalid and must be repeated.

Before the test, a tape measure is used to accurately measure the subject’s lower limb length (straight-line distance from the anterior superior iliac spine to the medial malleolus) as a standardized parameter, and eight-directional scale lines with uniform spacing are drawn on the surface of the testing platform. Each direction undergoes three valid trials, with the maximum reaching distance recorded and substituted into the dynamic stability index calculation (reaching distance/lower limb length × 100%). After completing independent tests for both lower limbs, by comparing inter-directional differences, bilateral symmetry, and performance characteristics in specific directions, and referring to the movement trajectories of the supporting and non-supporting legs at the eight testing direction points marked in the schematic diagram of the decomposed movements in Figure 4, a comprehensive evaluation of the directional characteristics of dynamic stability and bilateral functional coordination can be achieved (Al Attar et al., 2022).

Forward	Forward 45 °	lateral 90°	Backward 45°	Backward	Backward 45° (opposite)	Contralateral lateral 90°	forward 45°(opposite)
							

Figure 4 8 - Point Star Offset Test

3.2.2.2 Countermovement Jump

The participant begins in a standing position with feet shoulder-width apart and arms relaxed. Upon initiation, the athlete rapidly performs a countermovement by flexing the hips and knees to approximately 90° between the trunk and thighs, followed by explosive vertical propulsion through coordinated hip and knee extension, synchronized with upward arm swing to ear level (Hou et al., 2025). During the airborne phase, the body remains upright, and upon landing, the athlete transitions from forefoot to full-foot contact while maintaining stability, with post-landing knee flexion limited to ≤30° to minimize impact forces (Morin et al., 2011) (see Figure 5 for movement breakdown).

Force plates are utilized to record ground reaction forces (GRF) across all phases (countermovement, takeoff, and landing) (Myer et al., 2008). Jump height is calculated via the impulse-momentum method by integrating force-time data from the countermovement phase to takeoff (Weyand et al., 2000). Key parameters—including rate of force development (RFD), peak force magnitude, force-time curve symmetry, and force attenuation gradients during the initial 200 ms of landing—are analyzed to quantify lower limb stiffness, neuromuscular coordination, and dynamic stability. Notably, landing-phase force decay patterns correlate with knee joint stability and serve as predictive indicators of injury risk (Higashihara et al., 2018; Myer et al., 2011).

Figure 5 Countermovement Jump

3.2.2.3 Single - Leg Countermovement Jump

Participants stand on one leg on a force platform, with the non-supporting leg flexed at approximately 90° at the knee and hands on hips to maintain an upright posture (Sharrock et al., 2011). At the start of the test, subjects perform a rapid countermovement by coordinated flexion of the hip and knee (with a trunk-thigh angle of approximately 45°), followed by an explosive single-leg extension to jump vertically, synchronizing arm swing to enhance momentum. During the aerial phase, a neutral pelvic position must be maintained. Upon landing, subjects make contact with the forefoot and maintain knee flexion ≤25°, avoiding compensatory trunk tilt or swinging of the non-supporting leg throughout the movement (Hibbs et al., 2008), the decomposed movements are shown in Figure 6.

Front view | Side view

Figure 6 Single - Leg Countermovement Jump

3.2.3 Skills Measurement

3.2.3.1 Biomechanical Application and Kinematic Analysis of Motion Markers

This study will employ the TecnoBody D-WALL 3D motion capture system, which is equipped with 12 cameras operating at a frequency of 200 Hz. The system will track retroreflective markers, whose placement strictly adheres to the standards established by the International Society of Biomechanics (ISB) (Wu et al., 2002). As illustrated in (Table 12, Figure7a and 7b), these markers will be precisely positioned at key joint sites of beginner female gymnasts, including the ankle, knee, hip, shoulder, elbow, and wrist joints, as well as the thoracic and lumbar spine regions. As emphasized by Sadeghi et al., (2021), this meticulous marker placement is designed to comprehensively capture detailed movement patterns.

Given that all subjects are female, the process of attaching markers will be exclusively carried out by female researchers. Additionally, the subjects are required to wear gymnastic uniforms and gymnastic shoes during the test. A comparative analysis of the subjects' performance before and after the intervention will be conducted, with a primary focus on evaluating stability during rotational movements and jumping skills. This aligns with the research direction of Pupo et al., (2012). This methodology will facilitate a profound understanding of how interventions impact the gymnasts' performance in these critical movement segments.

Table 12: Marker Positions and Names

Body Part	Marker Position	Marker Code
Head	On the head, above the left/right ear.	A1/A2
	On the head, at the front center.	A3
Trunk	Superior end of sternum	B1
	Spinous process of second thoracic vertebra	B2
	Spinous process of tenth thoracic vertebra	B3
	Left/Right 12th Rib	B4/B5
Upper Limb	Left/Right Acromion	C1/C2
	Left/Right Lateral Epicondyle of Humerus	C3/C4
	Left/Right Medial Epicondyle of Humerus	C5/C6
	Left/Right Styloid Process of Radius	C7/C8
	Left/Right Styloid Process of Ulna	C9/C10
	Left/Right Head of 2nd Metacarpal	C11/C12
Pelvis	Left/Right Anterior Superior Iliac Spine	D1/D2
	Left/Right Posterior Superior Iliac Spine	D3/D4
	Left/Right Highest Point of Iliac Crest	D5/D6
	Midpoint between Spinous Processes of L4 and L5	D7
Lower Limb	Left/Right Thigh Point	E1/E2
	Left/Right Lateral Condyle of Femur	E3/E4
	Left/Right Medial Condyle of Femur	E5/E6
	Left/Right Anterior Leg (Tibial Tuberosity)	E7/E8
	Left/Right Lateral Malleolus	E9/E10
	Left/Right Medial Malleolus of Tibia	E11/E12
	Left/Right Heel Point (at the Same Height as Toe Point)	E13/E14
	Left/Right 1st Metatarsal Point	E15/E16
	Left/Right 5th Metatarsal Point	E17/E18
	Left/Right Toe Tip (Midpoint between 2nd and 3rd Metatarsal)	E19/E20

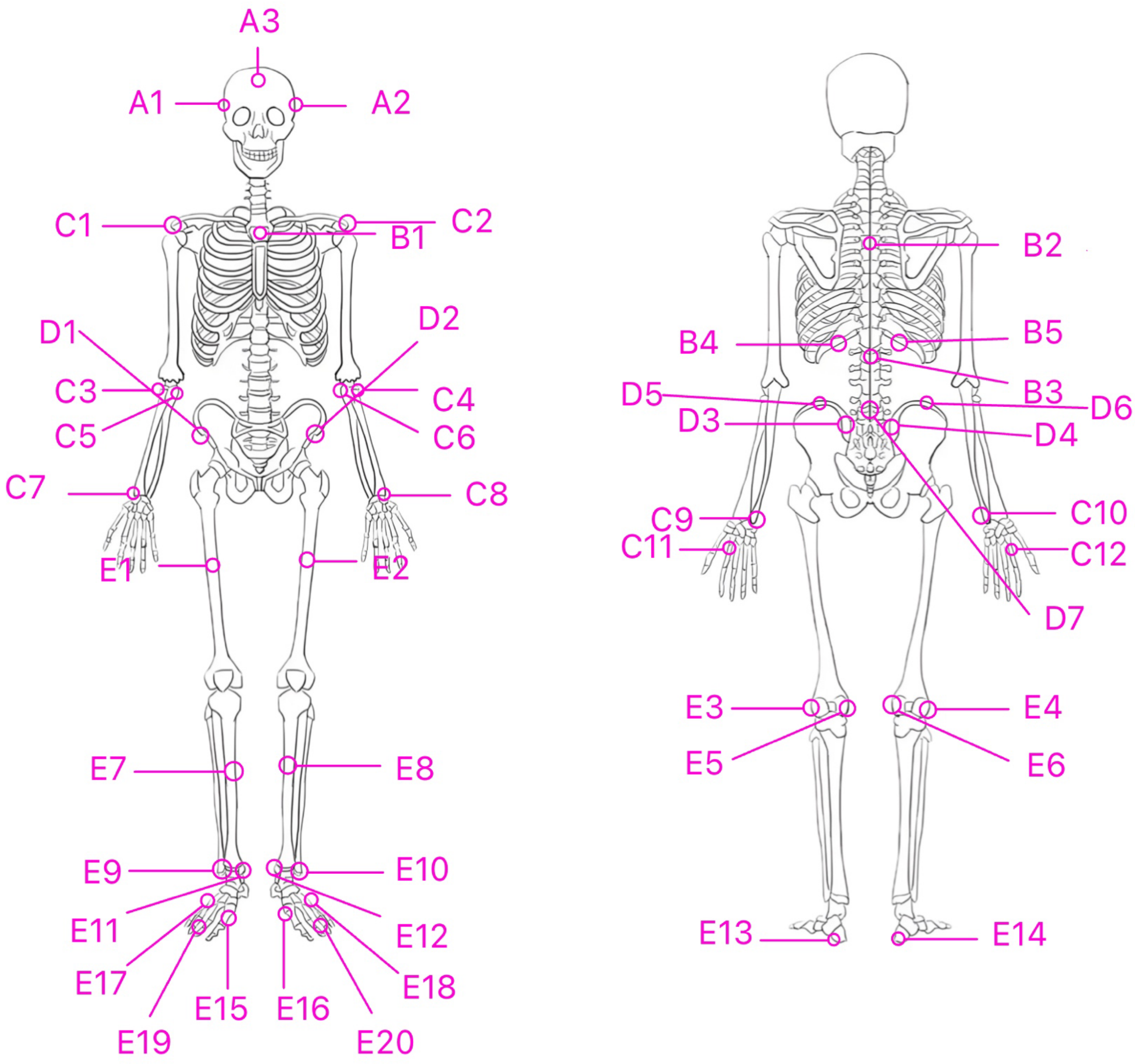


Figure 7a Placement of marker attachment on participants. The red points in the diagram indicate the joint areas where marks need to be pasted.

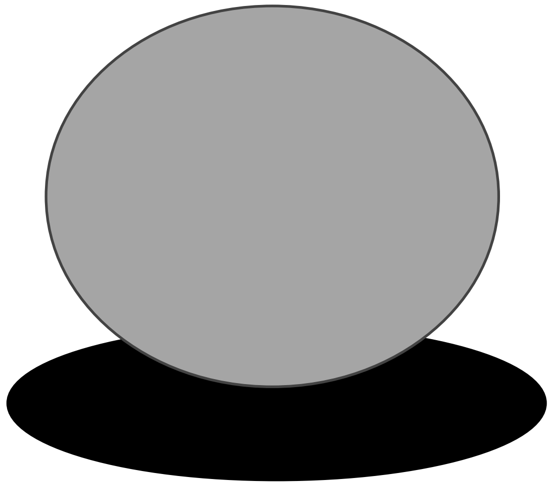


Figure 7b The marker that will be used to attached on the participant’s body. Marks are typically reflective materials or high-contrast stickers applied to key observation sites on athletes' bodies (e.g., joints or motion-sensitive areas) for biomechanical analysis. These visual markers assist technical devices such as cameras and sensors in precisely tracking body movement trajectories by providing distinct visual references, enabling accurate capture of motion patterns for performance

3.2.3.2 Measurement of Straight Jump 360° Turn

Participants start in an upright position with feet together and arms raised overhead. During the test, they swing their arms backward, perform a natural squat, and execute an explosive vertical jump upward, synchronizing arm movement to generate momentum. Upon reaching the aerial phase, subjects rapidly engage core muscles to complete a 360° horizontal rotation around the vertical axis, maintaining stable head and gaze direction to control the rotation axis. When landing, contact is made first with the forefoot, transitioning to full-foot support, while maintaining knee flexion ≤30°, avoiding lateral hip displacement, and keeping the trunk upright to absorb impact forces (Joseph, 2012). The entire movement must ensure continuity among the takeoff, rotation, and landing phases, with no loss of balance or deviation in the rotation axis, the decomposed movements are shown in Figure 8.

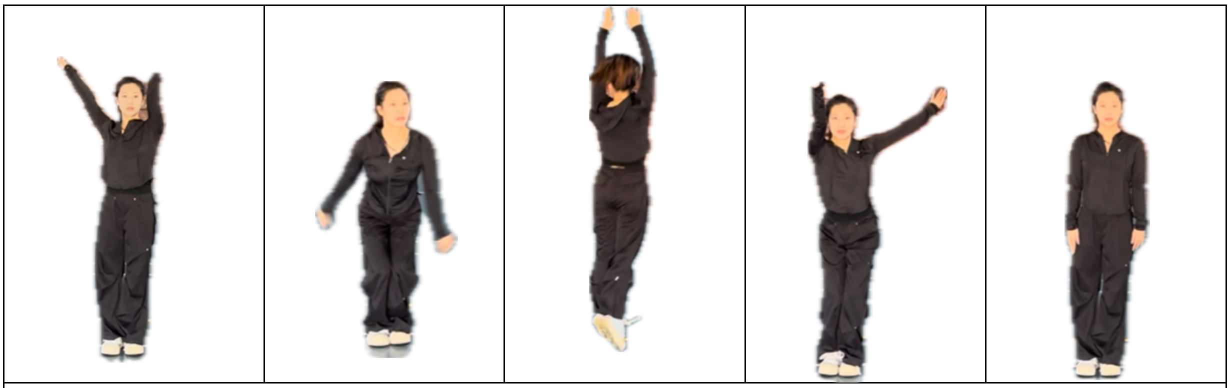


Figure 8 Straight Jump 360° Turn

3.2.3.2.1 Center of Gravity Deviation

The athlete executes a two-leg takeoff and completes a 360° aerial rotation around the hip joint as the axis, requiring the maintenance of body balance upon landing. During the test, this metric is defined as the maximum distance by which the three-dimensional displacement of the center of gravity (COG) deviates from the ideal rotational path (Hechenblaikner, 2024). Dynamic Balance Control: Smaller values indicate stronger ability of the central nervous system to regulate aerial posture and higher landing stability. Biological Explanation: The mechanical model is expressed as

$$D = \sqrt{(X\,real - X\,ideal)^2 + (y\,real\ - y\,ideal)^2 + (Z\,real - Z\,ideal)^2}$$

where X, Y, Z represent the actual COG coordinates versus the ideal trajectory coordinates (Etkin & Reid, 1995).

3.2.3.2.2 Joint Angle Variation

Student participants need to analyze angular fluctuations of hip, knee, and ankle joints during the aerial phase of two-footed vertical jumps with rotation. These fluctuations serve as crucial performance indicators: A coefficient of variation (CV) below 8% (professional athlete standard) suggests efficient lower limb coordination, while CV exceeding 12% typically indicates compensatory muscle strategies (e.g., excessive quadriceps activation may increase patellar tendon stress) (Cazzola et al., 2016). Angular fluctuations also serve as an energy loss indicator, positively correlated with muscular work through the theoretical model $E_{loss}= k\cdot\Delta\theta^2$ (Ditroilo et al., 2011). For measurement, 200Hz high-speed cameras will capture joint angular velocity curves to calculate CV. Elevated CV values reflect insufficient hamstring-gluteal complex stiffness, indicating the need for targeted strength and neuromuscular coordination training.

3.2.3.2.3 Vertical Jump Efficiency

This student participimpant will be evaluate the energy conversion efficiency of lower limb muscles during the jumping-rotating-landing process (e.g., the ratio of squat jump height to ground reaction force), where a power output efficiency exceeding 85% indicates excellent lower limb stiffness and neuromuscular coordination (Markovic & Mikulic, 2010). This metric serves as a training monitoring parameter, and optimization of this efficiency is shown to enhance jumping height. The biomechanical model is expressed as:

Efficiency = $\frac{Jump\ Height}{Ground\ Reaction\ Force \cdot cos(\theta)}$

where the ideal take-off angle θ is approximately 30°.

3.2.3.2.4 Landing Impact Force (N)

During the landing phase, the peak value of vertical impact force in participants is measured (simulating sudden stop scenarios in competitions), serving as an indicator of lower limb cushioning ability. Injury Prevention Indicator: An impact force below 1,200 N reduces the risk of Achilles tendon injury by 30% (Joseph, 2012), while forces exceeding 1,500 N typically indicate abnormal landing posture (e.g., inward knee buckling leading to stress concentration), providing a basis for technical optimization. The mechanical cushioning model is expressed as:

$F_{buffer} = \frac{mgh}{t^2}$

where *t* represents cushioning time (ideal value < 0.3 seconds). This model provides a quantitative framework for analyzing the relationship between impact force and motor control efficiency.

3.2.3.3 Measurement of Standing Single - leg 360° turn

Participants assume a split stance position with the front leg flexed at 20–30°, weight evenly distributed over the supporting leg, the corresponding arm extended forward, and the contralateral arm naturally positioned at the side. At the start of the test, using the supporting leg as the axis of rotation, participants complete a 360° horizontal rotation around the vertical axis at a constant speed through coordinated control of the hip joint and core muscles. Throughout the movement, fixed head orientation and gaze direction must be maintained to stabilize the rotational axis, while avoiding trunk flexion, extension, or lateral deviation (Fukata et al., 2025). Upon returning to the starting posture after rotation, the trial is deemed valid if there is no displacement of the supporting foot, the non-supporting leg does not touch the ground, and no loss of balance or sway occurs, the decomposed movements are shown in Figure 9.

Figure 9 Standing Single - leg 360° turn

3.2.3.3.1 Center of Gravity Deviation

The student participant completes a 360° rotation around the axis of one leg, with the other leg off the ground, and maintains static balance. During the test, the student participant must keep the torso stable during high-speed rotation to avoid imbalance caused by the deviation of the center of gravity. To assess performance, the three-dimensional displacement of the center of mass is tracked via an Inertial Measurement Unit (IMU), and the overlap degree between the actual trajectory and the ideal path is calculated using the formula $D = \sqrt{(\text{X real} - \text{X ideal})^2 + (\text{y real} - \text{y ideal})^2 + (\text{Z real} - \text{Z ideal})^2}$; smaller values indicate higher neuromuscular coordination and stronger action stability (Farana et al., 2023). The Vicon high-speed camera system (200 Hz) captures the movement trajectory, and center of mass deviation is calculated in combination with an inverse dynamics model, while ground reaction force is measured by a Force Plate (sampling rate 1 kHz) to provide biomechanical validation of balance control (Karatsidis et al., 2019).

3.2.3.3.2 Body Oscillation Amplitude (m)

During the dynamic single-leg support rotation, student participants are required to maintain the other leg completely off the ground while keeping the spine in a stable neutral position, with measurements taken for the maximum lateral/longitudinal displacement of the torso and lower limbs (e.g., lateral sway of the upper body during rotation). This assessment evaluates core stability by reflecting the anti-interference capability of deep core muscle groups (e.g., transversus abdominis, multifidus) against rotational centrifugal force (Vasseljen et al., 2012). The oscillation amplitude serves as an action economy indicator, with a positive correlation to energy consumption—optimizing this parameter can enhance movement efficiency, as described by the theoretical model $Eloss=k\cdot A^2$ (where A represents oscillation amplitude). Using high-speed photography (≥200 Hz), movement trajectories are captured and combined with a rigid body dynamics model to calculate three-dimensional oscillation amplitudes. Insufficient activation of core muscles, as noted by Gribble et al., 2012, often leads to compensatory excessive abduction/adduction of the hip joint, highlighting the neuromuscular mechanisms underlying rotational stability.

3.2.3.3.3 Rotation Smoothness Index (°)

During the evaluation of an athlete's momentum coherence from the starting position to completing a 360° rotation—characterized by uniform rotation without deceleration or acceleration phases—the participant must maintain natural hanging of the upper limbs and avoid torso twisting as key action requirements (Fukata et al., 2025). A smoothness index (SI) > 85°, a benchmark for professional athletes, indicates optimal movement quality, while an SI < 70° signals muscle coordination disorders (e.g., mismatched force generation between the hamstrings and gluteus maximus). This metric correlates positively with rotational speed and landing stability, as described by the theoretical model $v = \frac{2\pi\cdot R}{T}$ (where T is the rotation period) (Kuo & Donelan, 2010). To quantify movement smoothness, the joint angular velocity curve is analyzed via Fourier transform using the formula SI = $\frac{1}{T}\int_0^T |\theta(t)|dt$), which captures deviations from uniform rotation. Neurologically, the cerebellum-basal ganglia loop regulates movement rhythm; abnormal neural discharges within this circuit can disrupt speed consistency, highlighting the neuromuscular mechanisms underlying rotational control and competitive performance optimization (Taiar et al., 2022).

3.2.3.3.4 Landing Impact Force (N)

After a 360° rotation, vertical impact force at landing is measured with requirements for slightly bent knees and ankle cushioning. An impact force < 1000 N signals high lower limb cushioning efficiency, reducing Achilles tendon injury risk (model: $F_{buffer}= \frac{mgh}{t^2}$). Research shows impact force negatively correlates with the coordination of take-off height and rotation speed (Green, 2006).

Using an impact sensor, peak vertical force is recorded, and cushioning efficiency is calculated via Efficiency=$\frac{Fmax-Favg}{Fmax}$. Stiffer hamstring-gluteus muscles correlate with lower impact force, offering a basis for technique optimization and injury prevention by linking force measurements to muscle function (Mojaddarasil & Sadigh, 2021b).

3.3 STUDY AREA

The location of the training and test will be conducted at Beijing Sport University's North Gymnasium, a 'Fédération International de Gymnasium' -certified facility equipped with:

1. Olympic-grade balance beams (10 cm width, 5 m length).
2. Spring floors (Ariake, Japan) for jump training.
3. Climate-controlled environment (20–22°C, 50–60% humidity).

3.4 STUDY POPULATION

The target population for this study is newly registered female university students (aged 18 to 22), who are enrolled in the gymnastic class as part of their physical education degree programme.

3.5 SUBJECT CRITERIA

3.5.1 Inclusion criteria

The inclusion criteria for the study population are as follows:

1. Females

2. Age ranged between 18 -22 years old, normal body mass index (BMI) (18.5 -25kg/m²) (Traczyk et al., 2023).

3. Undergraduate students of physical education at Beijing Sport University.

4. No prior systematic gymnastics training (or with ≤ 1 year of systematic training experience), and no history of congenital diseases or musculoskeletal injuries.

3.5.2 Exclusion Criteria

1. Participants suffering from acute or chronic musculoskeletal injuries (lasting for 6 months or more), neurological disorders (such as epilepsy), or vestibular dysfunction.

2. Ranked athletes or elite athletes.

3. Participants with poor compliance (< 80%) who are unable to complete the 8 - week exercise intervention program.

4. Individuals who have recently undergone or are scheduled to undergo surgery within three months.

3.5.3 Withdrawal Criteria

Participation in this study is entirely voluntary. Participants may refuse to participate in this study or stop participating in this study at any time without penalty or loss of benefits to which they are otherwise entitled. An example of this would be if a subject develops an illness during the intervention. The research team may also stop their participation without their consent if they breach the study eligibility criteria in any way.

3.6 Sample Size Estimation

Using G - power 3.1 (Figure 10), the study focuses on time (within - subject factor), group (between - subject factor), and their interaction effects. The effect size is set to medium (0.35), with an alpha value of 0.05 and a statistical power of 0.80. A total of four groups will be included (static balance, dynamic balance, combined static and dynamic balance, and a control group), with measurements conducted twice, pre - and post - intervention. The calculated sample size is 52 participants. Considering a dropout rate of 15%, 60 participants will be recruited. Participants will be randomly assigned to four groups, with 15 participants in each group. Since the total dropout rate applies uniformly and participants are equally distributed across the four groups, each group's dropout rate is also 15%.

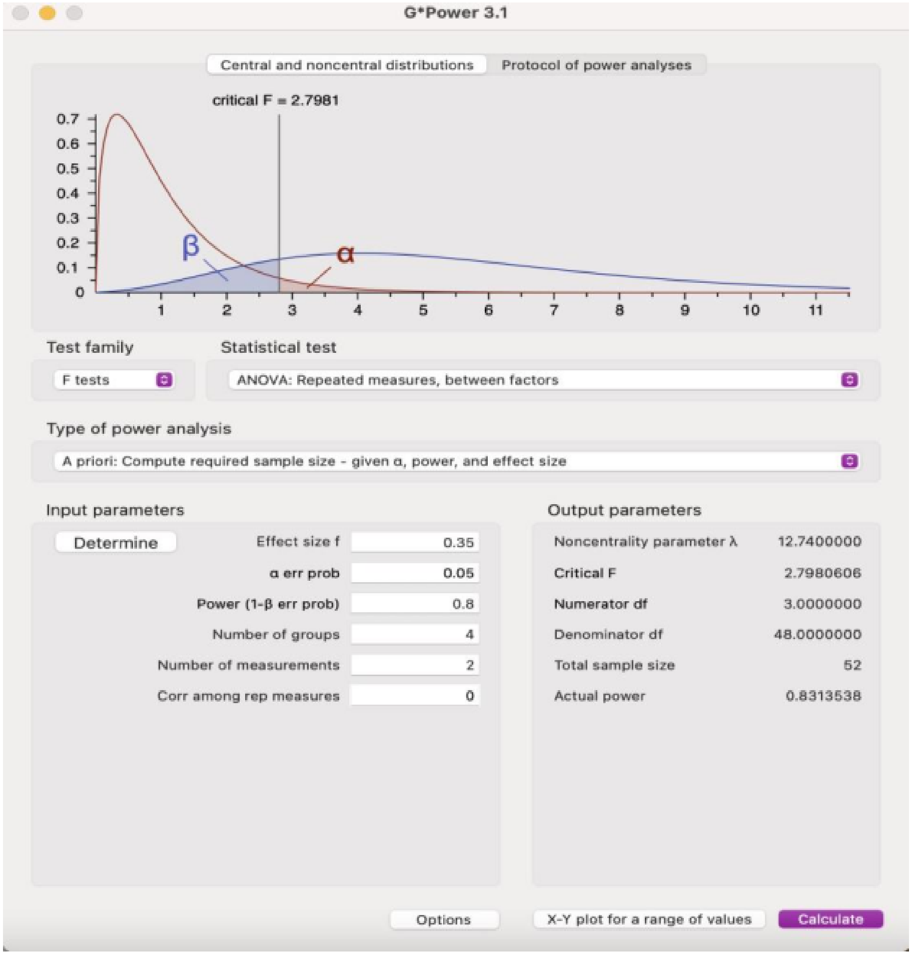


Figure 10 Flow chart of the G-power

3.7 SAMPLING METHOD AND SUBJECT RECRUITMENT

We will use convenience sampling to recruit participants, ensuring that all participants are female beginner gymnasts meeting the inclusion criteria. Recruitment will be conducted with prior approval from the Gymnastics Teaching and Research Department of Beijing Sport University. Additionally, recruitment posters will be displayed on the first-floor bulletin board of the university's teaching building. Eligible participants will be contacted via WeChat to confirm their interest in joining the study. Group allocation will be conducted using a random number table. All participant information will remain strictly confidential unless required by law.

3.8 INTERVENTION METHODS

Participants in the SG intervention group will complete an 8-week training program consisting of Plank Support, Single-Leg Stance, Eyes-Closed Double-Leg Stance, and Half-Squat Exercise. The DG intervention group will engage in Landing Control Training, Balance Beam Walking, jumping onto the Balance Beam, and Squat-to-Stand Exercises. The SDG intervention group will perform Plank Support, Single-Leg Stance, Eyes-Closed Double-Leg Stance, Half-Squat Exercise, Landing Control Training, Balance Beam Walking, jumping onto the Balance Beam, and Squat-to-Stand Exercises. Each exercise will be repeated 3 times or the corresponding number of times per session, with each session lasting 15 minutes (including 30 minutes of dynamic and static balance exercises), conducted twice a week for 8 weeks. All participants will enroll simultaneously, and each group will be guided by qualified instructors. Before and after each training session, participants will wear a heart rate monitor (Xiaomi Smart Band) on their wrist to ensure adherence to the prescribed training intensity outlined in Tables 13, 14, and 15. Additionally, participants may adjust their limb positions and movement intensity based on their physical condition. At the end of each session, training logs will be completed to document the activities. Only data from participants who adhere to at least 80% of the prescribed training program will be included in the analysis.

Participants in the control group (CG) will continue their regular training routine as detailed in Tables 7 and 8. They will be advised to maintain their usual daily activities without incorporating any additional exercises.

Table 13: Static balance training intervention content (n=15)

Week	content	Minutes/ Groups	Inter-group Rest Duration	Training duration	HR Monitoring Indicators	Heart Rate Monitoring Equipment	Intervention time	Heart rate range	Equipment
W 1	baseline test								
W 2-3	①Double leg stand ②Single leg stand	1/3	Rest for 2 minutes	15minutes	Resting Heart Rate (Before Training)/Maximum Heart Rate/Maximum Heart Rate	Xiaomi Smart Band	8 weeks, 2 times per week, 15 minutes each time	80bpm-100bpm	Balance board、BOSU ball
W 4	①Eyes-closed double-leg stance ②Plank support	1/3	Rest for 2 minutes	15minutes				80bpm-110bpm	Balance board 、 BOSU ball、Gymnastic mat
W 5	①Eyes-closed Single-leg stance ②Half Squat Exercise	1/3	Rest for 2 minutes	15minutes				80bpm-110bpm	Gymnastic mat、Balance board、BOSU ball
W 6	①Jumping onto BOSU ball + Eyes-closed double-leg stance ②Single-Leg Standing Leg + Leg Lift Exercise	1/3	Rest for 2 minutes	15minutes				80bpm-120bpm	Balance board、BOSU ball
W 7	①Single-Leg Standing Leg + Leg Lift Exercise ② Single-Leg Standing Pointe Exercise	1/3	Rest for 2 minutes	15minutes				80bpm-120bpm	Gymnastics ball、balance board、BOSU ball
W 8	Post test								

Table 14: Dynamic balance training intervention content (n=15)

Week	content	Times/ Groups	Inter-group Rest Duration	Training duration	HR Monitoring Indicators	Heart Rate Monitoring Equipment	Intervention time	Heart rate range	Equipment
W 1	baseline test								
W 2-3	①Jump in multiple directions on one leg ② Half squat exercise	8/3	Rest for 2 minutes	15 minutes	Resting Heart Rate (Before Training)/Maximum Heart Rate/Maximum Heart Rate	Xiaomi Smart Band	8 weeks, 2 times per week, 15 minutes each time	90bpm-110bpm	Gymnastic mat、Balance beam
W 4	①Jumping onto a low balance beam ②Half squat exercise	8/3	Rest for 2 minutes	15 minutes				90bpm-110bpm	Balance beam、Balance board、BOSU ball
W 5	①Jumping onto BOSU ball ② Half squat-to-stand and catch-and-throw ball exercise	8/3	Rest for 2 minutes	15 minutes				90bpm-120bpm	Balance board、BOSU ball
W 6	①Practice of jumping with rotation ②Plank and convert to two-hand support	8/3	Rest for 2 minutes	15 minutes				90bpm-120bpm	Gymnastics ball、balance board、BOSU ball
W7	①Walking on the Balance Beam ②Landing control training	5/3	Rest for 2 minutes	15 minutes				90bpm-120bpm	Gymnastic mat、Balance beam
W 8	Post test								

Table 15: The combination of static and dynamic balance training content (n=15)

Week	content	Times/ Minutes	Groups	Inter-group Rest Duration	Training duration	HR Monitoring Indicators	Heart Rate Monitoring Equipment	Intervention time	Heart rate range	Equipment
W 1	baseline test									
W 2-3	①Single-leg stance+ Leg - lifting exercise ②Half squat exercise + Throwing - catching ball exercise	2min 10times	3	Rest for 2 minutes	30 minutes	Resting Heart Rate (Before Training)/Maximum Heart Rate/Maximum Heart Rate	Xiaomi Smart Band	8 weeks, 2 times per week, 15 minutes each time	90bpm-110bpm	Gymnastic mat、Balance beam
W 4	①Jumping onto a low balance beam + Walking on the Balance Beam + Landing control training ②Half Squat Exercise + Throwing - catching ball exercise	10times 10times	3	Rest for 2 minutes	30 minutes				90bpm-110bpm	Balance beam、Balance board、BOSU ball
W 5	①Jumping onto BOSU ball + Double-leg stance ②Plank and convert to two-hand support	10times （1minutes） 10times	3	Rest for 2 minutes	30 minutes				90bpm-120bpm	Balance board、BOSU ball
W 6	①Jump training + Jumping with rotation ②Plank and convert to two-hand support + Plank support	10times 10times （1minutes）	3	Rest for 2 minutes	30 minutes				90bpm-120bpm	Gymnastics ball 、balance board、BOSU ball
W 7	①Jumping onto a low balance beam + Walking on the Balance Beam + Landing control training ②Forward roll + swallow balance	10times 10times	3	Rest for 2 minutes	30 minutes				90bpm-120bpm	Gymnastic mat、Balance beam
W 8	Post test									

3.8.1 Safety consideration

To ensure safety throughout the study, comprehensive measures were implemented across all stages: Prior to the experiment, participants were subjected to thorough health screenings, including medical history reviews and baseline physical assessments (e.g., BMI, musculoskeletal evaluations), to confirm eligibility and identify potential risks. Training sessions emphasized the importance of proper warm-up routines, standardized movement execution, and immediate reporting of discomfort, with all participants signing written documents to acknowledge risks, benefits, and withdrawal rights. During the intervention, training took place in a FIG-certified facility equipped with Olympic-grade apparatus and shock-absorbing flooring, supervised by three certified instructors. Real-time heart rate monitoring via Xiaomi Smart Bands ensured intensity levels remained within the prescribed range (80–140 bpm). For high-risk maneuvers such as balance beam dismounts, spotters and crash mats were deployed. In case of falls or acute pain, activities were immediately halted, and emergency protocols—including on-site first-aid personnel and equipment—were activated. Post-experiment, participants completed cooldown routines and underwent follow-up assessments to monitor for delayed soreness or adverse effects. All health and performance data were anonymized in accordance with institutional privacy policies to protect confidentiality. A continuous communication channel was maintained after the study to address any ongoing concerns.

3.8.2 Research tool

3.8.2.1 Kunwei Force Plate（jumping test）

The Kunwei force plate is a high-precision biomechanical measurement device widely used to assess jump performance, balance, and force development in athletes (Cormie et al., 2007). To scientifically evaluate the biomechanical performance of the countermovement jump (CMJ) and single-leg countermovement jump (SLCMJ), the standardized testing protocol using the

Kunwei Force Plate is as follows: Participants stand barefoot on the force plate with arms relaxed to complete a 10-second static calibration, recording baseline center of pressure (CoP) trajectories (re-test required if CoP drift exceeds 2 cm), with the system sampling rate set to 1000 Hz. For CMJ testing, participants perform rapid countermovement jumps from self-selected knee flexion depth to maximal height, landing symmetrically and stabilizing for 2 seconds, repeated 5 times (60-second rest intervals) (Markovic et al., 2004). For SLCMJ, participants execute single-leg jumps followed by ipsilateral landing with 3-second balance maintenance; failed trials (contralateral limb contact or external support) trigger retesting. The force plate continuously acquires vertical ground reaction force (vGRF) to calculate jump height (flight time method: $h = \frac{g \times t^2}{8}$) peak force (max vGRF), rate of force development (RFD: slope of force-time curve from 0-200 ms), and impulse (force-time integral). Real-time feedback on adjacent screens highlights critical metrics (e.g., RFD <3000 N/s—optimize ankle stiffness or bilateral peak force asymmetry >10%—adjust symmetry). Raw data undergo Butterworth low-pass filtering (50 Hz cutoff) and body weight normalization, with outliers excluded based on predefined criteria (e.g., pre-activation force exceeding 5% body weight or stabilization time >1.5 seconds). Processed datasets are encrypted and stored as CMJ/SLCMJ-Date-Subject. This protocol quantifies lower-limb explosive power, bilateral symmetry, and energy transfer efficiency (Gathercole et al., 2015), supporting athlete selection, training monitoring, and rehabilitation assessment (Meylan & Malatesta, 2009).

Figure 11 Kunwei Force Plate

3.8.2.2 Star Excursion Balance Test，（SEBT） stability test

The Star Excursion Balance Test (SEBT) is an effective tool for assessing dynamic balance in participants. During the test, the participant stands on one leg at the center of a star-shaped diagram and extends the other leg as far as possible in eight specific directions: anterior (ANT), anterolateral, lateral (LAT), posterolateral (PLAT), posterior (POST), posteromedial (PMED), medial (MED), and anteromedial (AMED) (Dendrinos et al., 2022). These directions are designed to evaluate balance in multiple planes. The maximum reach distance in each direction, normalized to the participant’s leg length, is used as an indicator of dynamic balance ability. Before the formal test, participants should undergo adequate practice trials to ensure proficiency and reliable data. During the test, the standing leg must remain stable, and the participant should avoid significant shifts in the center of gravity or loss of balance. Each direction should be tested multiple times, and the average of the best scores is used for analysis. Studies have shown that SEBT is highly sensitive in detecting functional deficits in the lower limbs, making it particularly useful for evaluating dynamic balance in athletes. Additionally, SEBT can be used to assess the impact of core strength training on dynamic balance. Research indicates that athletes who undergo core strength training exhibit significant improvements in SEBT performance, demonstrating that core training can enhance dynamic balance (Gong et al., 2023).

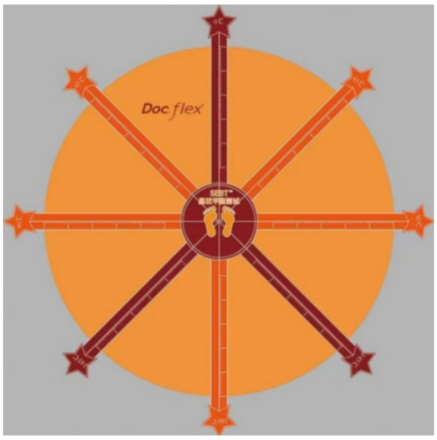


Figure 12 The Star Excursion Balance Test

3.8.2.3 TecnoBody 3D Motion Capture System（gymnastic performance movements）

To accurately assess the biomechanical parameters of the 360° straight jump turn and single-leg standing rotation, experimental procedures must integrate standardized protocols with real-time interaction: Test operators first instruct participants to stand still while reflective markers are affixed to anatomical landmarks (acromion, anterior superior iliac spine, greater trochanter, and lower limb joints), emphasizing that "markers must align with bone structures—avoid movement to prevent displacement (Soylu et al., 2025). During static calibration, participants are directed to stand naturally at the center of the force platform with arms relaxed and gaze forward, maintaining stillness for 10 seconds to establish the skeletal model. For formal testing, the straight jump turn requires execution under the command jump vertically, complete a 360° mid-air rotation, and land stably, while the single-leg rotation emphasizes upright posture on the support leg, stable trunk alignment, and 2-second balance maintenance post-rotation, with each movement repeated three times to ensure data reliability. During acquisition, the system provides real-time alerts such as "right knee marker occluded—adjust arm posture and retest" or "insufficient rotational angular velocity—reduce trunk compensation," ensuring movement standardization. Coaches view screens displaying the participant's center of mass trajectory (red) overlaid with the ideal biomechanical model (green), accompanied by feedback like "0.2-second delay in hip extension—optimize takeoff sequencing." Post-test, data undergoes quality control screening (e.g., center-of-mass deviation standard deviation <1.5 cm, marker occlusion rate <5%), encrypted and stored under the naming convention 'action-date' for subsequent biomechanical modeling and training optimization. This protocol, combining movement standardization, real-time correction, and multimodal data integration, enables granular analysis of rotational techniques (Bravi et al., 2023), supporting technical refinement and injury prevention research in disciplines such as artistic gymnastics and dance.

Figure 13(a) The 3D Motion Capture System

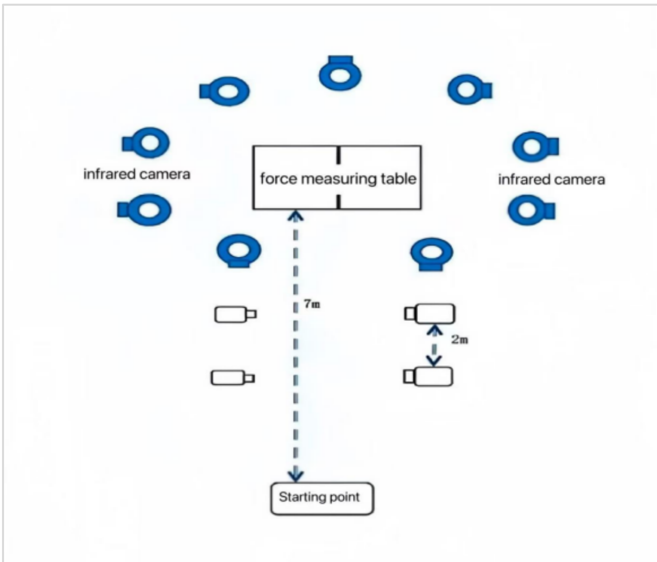


Figure 13(b) The Schematic placements of the motion capture system

3.8.2.4 Xiaomi Smart Band (Measure heart rate, exercise intensity)

Heart rate monitoring devices, such as the Xiaomi Smart Band, are commonly used to measure exercise intensity. The device is securely worn on the wrist. Before testing, participants undergo a 5-minute resting period to record their resting heart rate (RHR) as baseline data. During exercise, the device continuously records heart rate, activity duration, step count, calories burned, and distance covered (Concheiro-Moscoso et al., 2022). Depending on the type of exercise, such as running or interval training, the appropriate mode is selected to monitor heart rate in real time and assess intensity levels. These intensity levels are categorized into low intensity (50–60% of maximum heart rate, MHR), moderate intensity (60–70% of MHR), and high intensity (70–85% of MHR). For interval training, the device tracks heart rate fluctuations during different intensity phases. After the exercise, the ending heart rate (EHR) is recorded, and heart rate recovery (HRR) is monitored during a 5-minute cooldown period. By analyzing metrics such as average heart rate (AHR), maximum heart rate (MHR), and recovery rate, a comprehensive understanding of physiological responses and fitness levels can be obtained (Bravi et al., 2023).

The purpose of testing exercise intensity is to optimize training efficiency, evaluate cardiovascular function, ensure safety, monitor progress, and personalize training plans. By identifying different intensity zones, it is possible to target specific fitness goals, such as improving aerobic or anaerobic capacity, while minimizing risks and avoiding overtraining. This method provides data-driven personalized training strategies that not only enhance performance but also effectively monitor long-term fitness progress (Lugones-Sanchez et al., 2022).

Figure 14 Xiaomi Smart Band

3.8.3 Data analysis

To ensure the reliability and validity of the collected data, an effective database will first be established by importing the experimental data into an Excel spreadsheet. Subsequently, SPSS 29.0 software will be utilized for comprehensive statistical analysis.

Following this, a series of detailed statistical analyses will be conducted on the data related to jump performance and stability of beginner gymnasts. These analyses include:

1.Descriptive statistics to summarize the central tendencies and variability in the data.

2.Demographic variable analysis to explore the influence of participants' characteristics (e.g., age, BMI, or gender) on the outcomes.

3.Correlation analysis to examine the relationships between key variables, such as balance training methods and improvements in jump performance and stability.

4.Factor analysis to identify the underlying factors contributing to the observed improvements, thereby determining the most significant influencing variables.

This multi-layered analysis ensures a thorough understanding of the data and provides robust evidence for identifying the most effective training strategies for enhancing the jumping and stability performance of beginner gymnasts. Through this systematic approach, the research aims to generate scientifically valid and practically applicable insights.

CHAPTER 4

4.0 EXPECTED RESULTS

4.1 Anthropology

Table 16 Height, weight, and BMI at baseline and after 8 weeks in the static, dynamic, static and dynamic intervention and control groups. Data presented as mean ± SD.

<table>
<tr><th rowspan="3">Anthropometry</th><th colspan="8">Groups</th><th colspan="5" rowspan="2">Two-way repeated measures ANOVA</th><th rowspan="2">Bonferroni (p)</th></tr>
<tr><th colspan="2">Static</th><th colspan="2">Dynamic</th><th colspan="2">Static + Dynamic</th><th colspan="2">Control</th></tr>
<tr><th>B</th><th>W8</th><th>B</th><th>W8</th><th>B</th><th>W8</th><th>B</th><th>W8</th><th>SS</th><th>df</th><th>MS</th><th>F</th><th>p</th><th></th></tr>
<tr><td>Height</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5"></td><td></td></tr>
<tr><td>Weight (kg)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5"></td><td></td></tr>
<tr><td>BMI (kg/m²)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5"></td><td></td></tr>
</table>

B= Baseline, W=Week, ANOVA= Analysis of variance; SS=Sum of squares; df= degrees of freedom, MS=Mean square, F= F-test statistical value, $p<0.05$ denotes significance diffe

4.2 Jumping ability test results

Table 17 Countermovement jump (CMJ) and single-leg countermovement jump tests at baseline and after 8 weeks in the static intervention, dynamic intervention, static-dynamic intervention, and control groups. Data presented as mean ± SD.

<table>
<tr><th>Group</th><th>Test Type</th><th>Time Point</th><th>Jump Height (Mean ± SD)</th><th>Peak Force (N) (Mean ± SD)</th><th>Rate of Force Development (N·S) (Mean ± SD)</th><th>Impulse (N·s) (Mean ± SD)</th><th>Two-Way Repeated Measures ANOVA</th><th>Bonferroni (p)</th></tr>
<tr><td rowspan="4">Static balance group</td><td rowspan="2">Countermovement jump</td><td>B</td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>W8</td></tr>
<tr><td rowspan="2">Single-leg countermovement jump</td><td>B</td></tr>
<tr><td>W8</td></tr>
<tr><td rowspan="4">Dynamic balance group</td><td rowspan="2">Countermovement jump</td><td>B</td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>W8</td></tr>
<tr><td rowspan="2">Single-leg countermovement jump</td><td>B</td></tr>
<tr><td>W8</td></tr>
<tr><td rowspan="4">Static and Dynamic balance group</td><td rowspan="2">Countermovement jump</td><td>B</td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>W8</td></tr>
<tr><td rowspan="2">Single-leg countermovement jump</td><td>B</td></tr>
<tr><td>W8</td></tr>
<tr><td rowspan="4">Control group</td><td rowspan="2">Countermovement jump</td><td>B</td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>W8</td></tr>
<tr><td rowspan="2">Single-leg countermovement jump</td><td>B</td></tr>
<tr><td>W8</td></tr>
</table>

4.3 Stability test results

Table 18 Eight-point Star Offset stability test results at baseline and 8 weeks postintervention in the static intervention, dynamic intervention, static-dynamic intervention, and control groups. Data presented as mean ± SD.

Group	Test Type	Time Point	Anterior reach	posteromedial reach	composite score	Two-Way Repeated Measures ANOVA	Bonferroni (p)
Static balance group	SEBT(Pre-Test)	B					
		W8					
	SEBT(Post-Test)	B					
		W8					
Dynamic balance group	SEBT(Pre-Test)	B					
		W8					
	SEBT(Post-Test)	B					
		W8					
Static and Dynamic balance group	SEBT(Pre-Test)	B					
		W8					
	SEBT(Post-Test)	B					
		W8					
Control group	SEBT(Pre-Test)	B					
		W8					
	SEBT(Post-Test)	B					
		W8					

4.4 Gymnastics skills test results

4.4.1 Straight jump 360 ° turn test results

Table 19 Straight jump 360 ° turn test results at baseline and 8 weeks postintervention in the static intervention, dynamic intervention, static-dynamic intervention, and control groups. Data presented as mean ± SD.

Group	Test Type	Time Point	Center of gravity deviation distance	Joint Angle variation (°)	Vertical Jump Efficiency (%)	Landing Impact Force (N)	Two-Way Repeated Measures ANOVA	Bonferroni (p)
Static balance group	Straight jump 360 ° turn (Pre-Test)	B						
		W8						
	Straight jump 360 ° turn (Post-Test)	B						
		W8						
Dynamic balance group	Straight jump 360 ° turn (Pre-Test)	B						
		W8						
	Straight jump 360 ° turn (Post-Test)	B						
		W8						
Static and Dynamic balance group	Straight jump 360 ° turn (Pre-Test)	B						
		W8						
	Straight jump 360 ° turn (Post-Test)	B						
		W8						
Control group	Straight jump 360 ° turn (Pre-Test)	B						
		W8						
	Straight jump 360 ° turn (Post-Test)	B						
		W8						

4.4.2 Standing Single-leg 360 ° turn test results

Table 20 Standing Single-leg 360 ° turn test results at baseline and 8 weeks postintervention in the static intervention, dynamic intervention, static-dynamic intervention, and control groups. Data presented as mean ± SD.

Group	Test Type	Time Point	Center of Gravity Deviation	Body Oscillation Amplitude (mm)	Rotation Smoothness Index (°)	Landing Impact Force (N)	Two-Way Repeated Measures ANOVA	Bonferroni (p)
Static balance group	Standing Single-leg 360 ° turn (Pre-Test)	B						
		W8						
	Standing Single-leg 360 ° turn (Post-Test)	B						
		W8						
Dynamic balance group	Standing Single-leg 360 ° turn (Pre-Test)	B						
		W8						
	Standing Single-leg 360 ° turn (Post-Test)	B						
		W8						
Static and Dynamic balance group	Standing Single-leg 360 ° turn (Pre-Test)	B						
		W8						
	Standing Single-leg 360 ° turn (Post-Test)	B						
		W8						
Control group	Standing Single-leg 360 ° turn (Pre-Test)	B						
		W8						
	Standing Single-leg 360 ° turn (Post-Test)	B						
		W8						

CHAPTER 5

5.0 SUMMARY OF THE RESEACH PROGRESS

5.1 Gantt chart and Milestone

Table 21 presents the time - planning for the PhD research project.

Table 21 Gantt chart of the research project

ACTIVITIES / MONTH	Oct 2024	Nov 204	Dec 2024	Jan 2025	Feb 2025	Mar 2025	Apr 2025	May 2025	June 2025	July 2025	Aug 2025	Sep 2025	Oct 2025	Nov 2025	Dec 2025	Jan 2026	Feb 2026	Mar 2026
Find research topic-Refine research title and discussion of project details																		
Preparing research proposal-Journal & article search from database - Research proposal write-up -Amend proposal follow supervisor's approval																		
Submit ethical application																		
Obtain ethical approval-Amend research proposal based on ethical																		
Manuscript Preparation - Systematic Review: " Lower Extremity Injury Prevention Through Balance and Flexibility Training in Gymnastics: Meta-Analysis"																		
Manuscript Preparation - " Mechanisms of Balance State Transition Influenced by Apparatus Contact Characteristics in Gymnastics: A Systematic Review"																		

Table 21 Gantt chart of the research project (continued)

ACTIVITIES / MONTH	Apr 2026	May 2026	June 2026	July 2026	Aug 2026	Sep 2026	Oct 2026	Nov 2026	Dec 2026	Jan 2027	Feb 2027	Mar 2027	Apr 2027	May 2027	June 2027	July 2027	Aug 2027	Sep 2027
Thesis write-up-Chapters 1-3	■	■	■															
Recruitment of study participants				■	■													
Experimentation and data collection						■	■	■	■	■	■							
Data entry and statistical analysis												■	■	■				
Thesis write-up - results												■	■	■	■			
Discussion, conclusion and abstract write-up - Submit draft to supervisor for approval and thesisamendment													■	■	■	■		
Thesis presentation-Prepare PowerPoint slides & presenter notes																	■	■
Thesis submission																	■	■

5.2 Milestone for Research Project

Table 22 presents the key research milestones of the Research Project, along with their corresponding cumulative project completion percentages.

Table 22 Milestone for Research Project

Research Activities	Date	Cumulative Project Completion Percentage (%)
Find research topic /Literature review	1/10/2024	5
Preparing research proposal	1/1/2025	10
Obtain ethical approval	1/6/2025	15
Balance training programme and systematic evaluation of jumping and stability	1/10/2025	20
Balance training programme and cross-sectional study of jumping and stability	1/1/2026	25
Recruitment of study participants	1/7/2026	40
Experimentation and data collection	1/9/2026	70
Data entry and statistical analysis	1/3/2027	80
Final research project, presentation of data	1/5/2027	90
Submission of research project	1/8/2027	100

5.3 BUDGET PROPOSAL

There is no grant available for this project. All facilities and equipment are supplied by the Beijing Sports University at no costs to the researchers.

5.4 ETHICAL CONSIDERATIONS

5.4.1 Subject vulnerability

In this study, participants may experience mild symptoms such as muscle fatigue, slight dizziness, or balance instability during the intervention. However, these symptoms typically subside within 24–48 hours after completing the training or testing. If participants experience any discomfort, appropriate medical care and interventions will be provided as needed. Throughout the training and testing period, participants' safety will be closely monitored. Medical laboratory officers and technicians trained in cardiopulmonary resuscitation (CPR) and basic life support (BLS) will always be on standby to ensure timely responses to any emergencies. Participants are free to withdraw from the study at any time without any obligations or penalties.

If these symptoms occur, they should immediately stop training and rest as needed. In the event of acute symptoms during the intervention, medical treatment will be promptly provided. Should a participant's condition worsen to the extent that hospitalization is required, the training will be suspended and resumed only after the participant's condition stabilizes. If the condition continues to deteriorate and medical professionals deem the participant unfit to continue, they will be excluded from the study to ensure their safety. The research team is committed to providing a safe environment and a supportive framework to safeguard the health and well-being of all participants throughout the study.

The participant will not be subjected to coercion or deception. All participants in this study are voluntary.

5.5 DECLARATION OF CONFLICT OF INTEREST

There are no conflicts of interest exist.

5.6 PRIVACY AND CONFIDENTIALITY

All information will be kept confidential by the researchers and will not be made publicly available unless disclosure is required by law. All electronic copies will be encrypted in a password protected medium in a portable storage. The data will be retained by the researchers for knowledge purposes only for at least 7 years until which will then be destroyed. Neither the name nor any identifying information will be used in any publication or presentation resulting from this study. Permission will be obtained before any videos or photographs taken.

5.7 COMMUNITY SENSITIVITIES AND BENEFITS

The physical fitness test used in this study may provide participants with health-related and balance training information. We recognize that some people might not respond well to treatments. As a result, we will discuss this with participants at the briefing and before getting their permission. In addition, participants will gain from increasing the knowledge in the balance training (static and dynamic) and its associated tests.

5.8 HONORARIUM AND INCENTIVES

This participation in this study is entirely voluntary with no honorarium provided to the participants.

5.9 OTHER ETHICAL REVIEW BOARD APROVAL

A letter of approval from Beijing Sports University, China has been obtained (Appendix1, page 131 to 132).

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APPENDIX

Appendix 1

北京体育大学
BEIJING SPORT UNIVERSITY

Permission

Beijing Sport University agrees to allow the use of athletes' data by Dr. Wang Yi from Universiti Sains Malaysia for the study titled "Research on Improving the Stability and Jumping Skills of Gymnastics Novices through Static and Dynamic Balance Training." Records of the subjects will be used solely for scientific research, and their privacy will be strictly protected.

School of Education, Beijing Sport University

北京体育大学
BEIJING SPORT UNIVERSITY

许可

北京体育大学体操教研室同意使用运动员的资料，由马来西亚理科大学的王熠博士进行“关于通过静态和动态平衡训练提高体操新手的稳定性和跳跃技能研究”。关于受试者记录仅用于科学研究，决不暴露受试者隐私。

北京体育大学体操教研室

Appendix 2


USM
APEX
北京体育大学
BEIJING SPORT UNIVERSITY
CALL FOR PARTICIPANTS
Requirements
• Females
• Age 18-22 years
• Undergraduate students of physical education
• No gymnastic background, non-athelete, no history of congenital diseases and muscle or skeleton injuries.
What will you need to do?
• Intervention: Balance training
• Intervention duration: 8 weeks
Location
•North Gymnasium, Beijing Sport University
Will you be compensated?
Yes!
• Professional teaching team to coach movements for all events in Beijing Sport University's Level 2 and 3 campus gymnastics competitions.
• Extra benefits: Postgraduate exam/IELTS resource packs; Irregular red envelopes in the WeChat group.
For more information, please contact:
Ms. Wang Yi.
Tel: 86 - 17316039914 (WeChat same number)
WhatsApp: 60 - 137002049


USM
APEX
北京体育大学
BEIJING SPORT UNIVERSITY
招募受试者
需求
• 女生
• 年龄 18-22 岁
• 体育教育专业本科生
• 没有体操背景，非运动员，无先天性疾病及肌肉或骨骼损伤史。
您需要做什么？
• 干预内容：平衡训练
• 干预周期：8 周
地点
• 北京体育大学北体操馆
您将会有奖励吗？
当然
• 你将获得北京体育大学专业的教练团队为您指导二、三级校园体操通级比赛的所有项目。
•额外福利：考研/雅思资料包支持；不定期在微信群发放红包.
想要获得更多信息，请联系：王熠.
手机号: 86 - 17316039914 (微信同号)