Effects of Unilateral and Bilateral Complex Training on the maximum strength, explosive power, and changing direction ability of volleyball players

Yan Sun

A Thesis Submitted in Partial Fulfillment of Requirements for
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The examining committee has unanimously approved this Thesis, submitted by Mr. Yan Sun , as a partial fulfillment of the requirements for the Doctor of Philosophy Exercise and Sport Science at Mahasarakham University

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ABSTRACT

Unilateral complex training involves focusing on one limb (single foot) and working independently in each training session. After conducting maximum strength training through the muscle contraction and work of the leg on that side, it is immediately followed by light-load rapid-strength training with a biomechanical movement pattern similar to the heavy-load resistance training movement on the same side. This is a training method that combines single-leg maximum strength and rapid-strength training to efficiently develop athletes' strength and explosive power. Volleyball is a sport that places high demands on lower-limb strength. The maximum strength, explosive power, and change-of-direction ability of the lower limbs are crucial for the performance of volleyball techniques and tactics.

Objective of the study is two:1. To compare before and after of the unilateral complex and bilateral complex training on the maximum strength, explosive power, and changing direction ability of volleyball players.2. To compare a group of unilateral and bilateral complex training on the maximum strength, explosive power, and changing direction ability of volleyball players.

The research subjects were male volleyball players from two universities, with 34 players from each university. The experimental group underwent unilateral compound training of the lower limbs, while the control group carried out bilateral compound training of the lower limbs. The training lasted for 8 weeks, with 2 training sessions per week, and each session lasting 80 minutes.

This study employed methods such as literature review, experimentation, testing, and statistical analysis. By measuring indicators of athletes including 1RM squat, Isometric Mid - Thigh Pull, Counter - Movement Jump, Drop Jump, 5 - meter sprint, 10-meter sprint, The speed of a jump-served ball, The speed of a jump-spiked ball, and 180º Change of Direction Speed, the effects of the two training methods were compared. The results showed that: By comparing the performance before and after the intragroup trials, it indicated that both unilateral compound training and bilateral compound training could effectively improve the athletes' maximum strength, explosive power, and change-of-direction ability after 8 weeks of intervention training. By comparing the improvement ranges before and after the inter-group experiments, it was shown that the unilateral compound training was more effective than the bilateral group in improving the performance of single-leg test items, as well as the 5 - 5-meter sprint and 10-meter sprint. The bilateral compound training had a greater improvement range in double-leg test items than the unilateral group. Overall, however, the effect of unilateral compound training was superior to that of bilateral compound training.

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Keyword : Unilateral Complex Training, Bilateral Complex Training, Maximum Strength, Explosive Power, Changing Direction Ability

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Yan Sun

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CHAPTER 1

INTRODUCTION

Background

Volleyball, as a high-intensity intermittent sport, places extremely high demands on athletes' maximum strength, explosive power, and changing direction ability. In 2019, the General Office of the State Council issued the "Outline for Building a Sports Strong Country" (State Council Bulletin of the People's Republic of China, 2019), which clearly proposed the development goals of China's competitive sports and international influence, proposed the construction of a sound and complete scientific training system, trained sports talents, and emphasized the comprehensive promotion of the popularization of football, basketball, and volleyball in China, and improved the scientific level of "three major balls" training. This shows that a scientific and systematic sports training system is particularly important. In 2020, the General Administration of Sport of China proposed the "Notice of the General Office of the General Administration of Sport on Further Strengthening Basic Physical Training to Make up for Physical Shortcomings" (Sports Department, 2020), indicating that physical fitness is an important influencing factor on sports performance. The competitive ability of high-level athletes consists of the following parts: excellent physical fitness, superb technical and tactical skills, strong psychological qualities, and rapid cognitive response ability. Physical fitness is the foundation for building the overall competitive level of athletes, and physical factors greatly affect the technical, psychological, and cognitive abilities of athletes. Strength and agility are important components of physical fitness, and explosive power and directional ability are the subordinate physical abilities of strength and agility, respectively. (Sheppard, J M. 2006) From a kinematic perspective, explosive force is the cumulative change in load state over a relatively short period of time; The ability to change direction, as a subordinate physical ability of sensitive qualities, refers to the ability of athletes to quickly change their speed and direction of movement under the condition of knowing the direction in advance. It includes the process of slowing down, changing direction, and accelerating again in a short period of time. The explosive power of the legs is closely related to the changing direction ability, and developing explosive power of the legs is one of the effective ways to improve the changing direction ability. (Sheppard, J M. 2006) Many team ball games involve a large amount of sprinting, changing direction and other movements, and the performance on the field is that athletes frequently complete high-intensity acceleration, deceleration, and changing direction movements (Ben Abdelkrim, N. 2010). Volleyball belongs to the competitive sport of net separation, and good physical fitness is the foundation for volleyball players to master and apply various techniques and tactics. With the rapid development and increasing perfection of modern volleyball techniques and tactics, as well as the overall trend of body enlargement and the popularity of strength based playing methods, higher requirements have been put forward for the physical conditions and various specialized physical fitness of volleyball players. In volleyball matches, athletes need to quickly pass, spike, and block the ball, and the time required to complete these movements is generally within 10 seconds. In terms of time and movement requirements, many technical movements in volleyball require quick explosive force. In addition, according to the characteristics of "fast and varied" modern volleyball gameplay, the ability to change direction and move has become a very important physical ability for volleyball players, reflected in the fast movement of front row players in moving blocks and back row players in receiving, spiking, adjusting passes, and other aspects (Zhuowen, Liu. 2020). So explosive power and directional mobility are very important in volleyball, and they play an irreplaceable role. The strength of both directly affects the competitive level of athletes, thereby affecting their sports performance.

The current volleyball agility training mainly focuses on multi-directional movement training (Chuang, C.H. 2022; Born, D.P. 2016; Jun, Yin. 2015), but this training method has proven to be effective but is also considered to have certain limitations Yuanyuan, Zhu. 2022), such as the inability to fully develop agility qualities and relatively less training on lower limb explosive power. Related studies have shown that better lower limb explosive power can help the body overcome internal and external resistance when rapidly changing direction and movement, thereby improving sensitivity, and it has been proven that explosive power is a key factor affecting sensitivity (Kovaleski, J. E. 2001; Peterson, M. D. 2006; Barnes, J. L. 2007). Therefore, how to scientifically improve the lower limb strength, explosive power, and changing direction ability of volleyball players has become an important issue in current training research.

With the continuous development of various aspects of physical fitness training, the training of lower limb strength is also constantly being improved, and it is also moving towards a more scientific and effective direction. In the past training process, coaches have used training methods and techniques such as reinforcement training and traditional resistance training to improve the lower limb strength level of students. However, due to various limitations, it is often difficult to achieve particularly satisfactory results during the training process. Currently, many studies use complex training to improve athletes' lower limb strength, which is highly recognized by coaches. The concept of "complex training" was first proposed by foreign scholars in the 1970s and applied in the training of high-level track and field athletes in the form of a "combination of speed and strength." Subsequently, it was widely used in many explosive-dominated sports (Fukunaga, T. 1997). Complex training refers to arranging plyometric training with similar biomechanics after resistance training to enhance the maximum strength and explosive power of athletes through post-activation potentiation (WEBER, K. R. 2006; Hao, L. 2019). Initially used to improve the lower limb strength of long jumpers, this method attracted the attention of many researchers due to its effectiveness in boosting explosive power and has since been applied to various sports (Liu, Y. 2021). Many studies suggest that complex training is more effective than single resistance training in developing athletes' rapid strength. Incorporating complex training into explosive sports can enhance athletic performance, reduce training time, and lower injury risks. However, experimental results on its effectiveness have shown inconsistencies. Therefore, how to arrange complex training more scientifically and efficiently remains a key focus in relevant research to improve athletes' strength and explosive power.

Meanwhile, previous studies on complex training have involved unilateral and bilateral complex training. Unilateral complex training (lower limbs) refers to training where muscle contraction and work are performed by one leg, such as lunge squats and single-leg jumps; bilateral complex training (lower limbs) involves simultaneous muscle contraction and work by both legs, such as bilateral squats and frog jumps. Young (2006) reported that bilateral vertical exercises (vertical jumps, squats, deadlifts, and Olympic weightlifting) produced weaker training effects in elite athletes. Although bilateral resistance training can effectively develop maximum strength, it shows low transfer effects on athletic performance in elite athletes. Cronin et al. (Cronin J, Ogden T, Lawton T, et al. 2007) found that the transfer effect of back squat maximum strength (23%-27%) on athletes' sprint ability was low (2-3%). Comparing intervention effects across different athlete levels, amateur athletes generally exhibit positive and significant responses, whereas high-level athletes show weaker effects. Many studies have shown that unilateral resistance training can effectively improve strength qualities and physical stability. Margaret, Jones. et al. (2012) pointed out in their research that unilateral strength training is more in line with the technical characteristics of most sports and can effectively promote the specialized development of strength. They believed that single-leg squats can be used as supplementary exercises for lower-limb strength training to reduce the risk of sports injuries. Similarly, research has shown that unilateral lower-limb strength training combined with explosive-power training can improve athletes' ability to change direction (Derrick, E. S. 2016), sprinting ability (McCurdy, K. W. 2005), and jumping ability (Gregory, C. B. 2019).Unilateral strength training refers to a training method that focuses on one side of the limb as the main force action mode, such as lunge squats, split leg squats, step steps, etc. Some researchers believe that the reason why unilateral training is more effective than bilateral training is due to the phenomenon of bilateral force loss. The phenomenon of bilateral force deficiency, also known as bilateral force deficiency, refers to the possibility that the sum of forces exerted during unilateral training in the human body may be greater than the sum of forces exerted during bilateral training. At present, there is relatively little research on the benefits of unilateral complex training. In practical research on unilateral and bilateral strength training, only a simple comparison of left and right legs was made, and resistance training or rapid strength training were conducted during training. There is still relatively little comparative analysis and research on the use of unilateral and bilateral training in complex training to effectively enhance the maximum strength and explosive power of volleyball players.

Based on this, this study aims to systematically compare the effects of unilateral and bilateral complex training on the maximum strength, explosive power, and changing direction ability of volleyball players, and clarify the action mechanisms and differences in training effects of different training modes. By designing scientific training programs, this study explores the effectiveness of unilateral and bilateral complex training in improving the lower limb strength, explosive power, and changing direction ability of volleyball players, providing an empirical basis for coaches to formulate personalized training plans. The implementation of this study can not only enrich the theoretical system of complex training and promote the innovative development of sports training methods but also provide scientific and personalized training programs for the strength training of volleyball players, improve athletes' competitive performance, and help enhance the level of volleyball sports. At the same time, it can provide reference for the training of other team ball sports.

Research Objectives

1. To compare the effects of unilateral complex training and bilateral complex training on the maximum strength, explosive power, and changing direction ability of volleyball players.

2. To compare the effects of unilateral complex training and bilateral complex training on the maximum strength, explosive power, and changing direction ability of a group of volleyball players.

Research Significant

1. Theoretical significance: Based on the concept of complex training, and using relevant theories such as sports biomechanics, sports physiology, and sports training, this study conducts theoretical analysis and exploration of the improvement of lower limb maximum strength, explosive power, and changing direction ability of volleyball athletes, providing relevant theoretical basis for selecting scientific and specific training methods and means.

2. Practical significance: The application and research of complex training with two different combination structures of lower limb unilateral and bilateral in the lower limb strength training of athletes in men's volleyball team, providing a reference basis for coaches in formulating strength training plans; Enriching strength training methods and means, making training more scientific and practical, improving and enhancing athletes in strength training, and providing strong support for cultivating more outstanding athletes.

Research Questions

1.What are the unilateral and bilateral complex training programs suitable for improving the lower limb strength of volleyball player?

2. What are the testing indicators for the training effectiveness of lower limb volleyball players' maximum strength, explosive power, and changing direction ability?

3. What is the experimental verification plan for the training effect of unilateral and bilateral complex training on the maximum strength, explosive power, and changing direction ability of the lower limbs of volleyball players?

Research Hypothesis

1.After unilateral and bilateral complex training, volleyball players have improved their lower limb maximum strength, explosive power, and changing direction ability.

2. The training effect of using unilateral complex training on the maximum strength, explosive power, and changing direction ability of the lower limbs of volleyball players is better than that of bilateral complex training.

Research Scope

1. Population

1.1 Research object: A comparative experimental study of the effects of unilateral complex training and bilateral complex training on the maximum strength, explosive power, and changing direction ability of volleyball players in the lower limbs.

1.2 Interview (research) subjects: Volleyball coaches, experts in sports training, and other fields.

1.3 Test subjects: University male volleyball players.

2. Sample

Phase 1: The main focus of this stage is to develop a single side complex training and dual side complex training plan for volleyball athletes, and to determine the maximum strength, explosive power, and changing direction ability testing indicators for volleyball athletes. Completed through expert interviews and questionnaire surveys. Expert Interview Method: Interviews were conducted with a total of 9 individuals, including coaches and experts, of whom 5 were invited to participate in the IOC survey. Questionnaire Survey Method: Questionnaires were distributed to an additional 12 individuals, including coaches and experts.

Phase 2: In this study, the sample size was calculated using G - Power software (Version 3.1.9.7) (http://www.gpower.hhu.de/). According to Cohen (2013), both the ideal statistical power and effect size should be higher than 0.8. Based on this standard, the α error prob was set at 0.05, the research power was set at 0.8, and the effect size was set at 0.8. The calculated sample size for each group was 27 subjects. On this basis, referring to the sample sizes of complex training related to this study (Guilherme, P. Berriel. 2022; Zhe, Chen. 2024; Kaixiang, Zhou 2022; Lei, Hao. 2019, etc.), and considering the dropout rate caused by injuries or accidents during the process, with the formula [sample size=calculated subjects/(1-20%)], the actual sample size n=calculated number of subjects/(1-20%), that is, $n=27÷0.8=33.75≈34$. Thus, the calculated sample size for each group was 34 subjects. Therefore, the final sample size of this experiment was $n=34×2=68$. A total of 87 volleyball players from Shanghai University and Shanghai University of Sport were eligible to participate in this experiment. It was planned to recruit 68 of them as experimental subjects, who were divided into an experimental group and a control group, with 34 athletes in each group. For the convenience of centralized intervention training, the lottery method was adopted to conduct the grouping by school in this paper. Eventually, in this study, 34 out of 48 male volleyball players from Shanghai University of Sport were selected to form the experimental group for unilateral complex training. 34 out of 46 volleyball male players from Shanghai University were selected to form the control group for bilateral complex training.

3. Scope of research content

This study includes two stages of research contents. The research content of the first stage is to formulate the unilateral complex training and bilateral complex training programs for the lower limbs of volleyball players through literature review, expert interviews and questionnaire surveys, and determine the test indicators for the maximum strength, explosive power and directional change ability of volleyball players. The research content of the second stage is to compare the effects of unilateral complex training and bilateral complex training on developing the maximum strength, explosive power and changing direction ability of the lower limbs of volleyball players through experiments.

4. Variables used in the study

4.1 Independent Variables

The independent variables of this study are lower limb strength training methods: Unilateral complex training and Bilateral Complex Training.

4.2 Dependent Variables

The dependent variable of this study is the test indicators of maximum strength, explosive power, and changing direction ability. The test indicators are as follows: 1RM squat, Isometric Mid-Thigh Pull (unilateral and bilateral), Counter-Movement Jump (unilateral and bilateral), Drop Jump (unilateral and bilateral), Sprint (5m and 10m), 180ºChange of Direction Speed, jump spike speed, Jump serve speed.

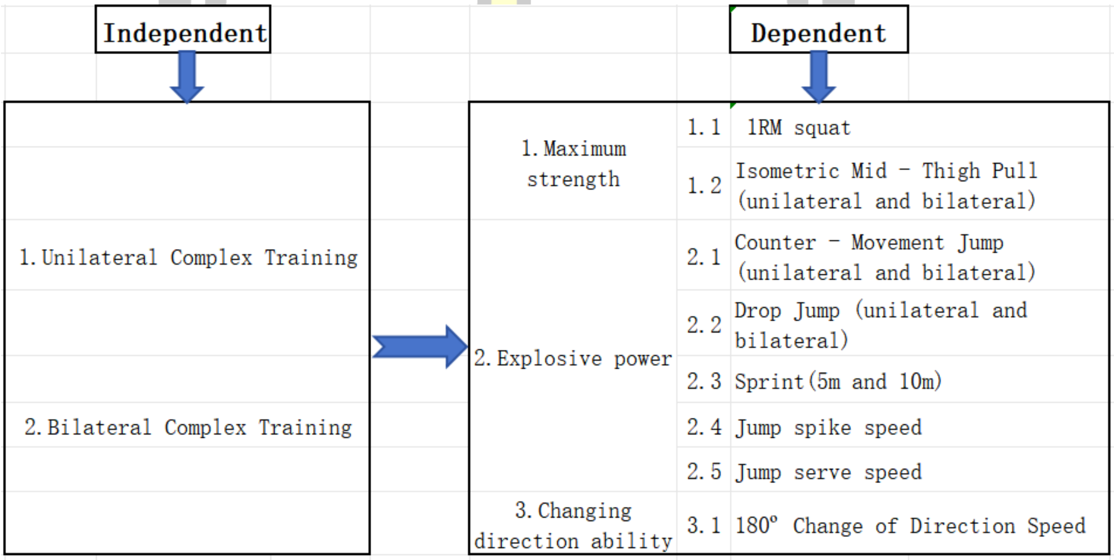

Figure 1 Research Variables

Note: The independent variables, dependent variables, and subcategories are described in detail in the “Definitions of Terms”.

Definitions of Terms

1. Complex training

Complex training is a training method designed to efficiently develop athletes' strength and explosive power, with its core lying in the organic combination of maximum strength training and fast strength training, namely the integration of traditional resistance training and plyometric training. Specifically, complex training is structured such that after completing high-load maximum strength training, athletes immediately perform low-load fast strength training with biomechanical movement patterns similar to those of the high-load resistance training. This approach leverages the highly activated state of the neuromuscular system following maximum strength training (i.e., the "post-activation potentiation" (PAP) effect) to further enhance the effectiveness of fast strength training. The theoretical basis of complex training is the post-activation potentiation (PAP) effect, which involves activating the neuromuscular system through high-intensity resistance training to enable muscles to generate greater force and speed during subsequent plyometric training. This effect typically reaches its peak within 3-10 minutes after maximum strength training, so the design of complex training requires strict control of rest time between two training sets. As a scientific and efficient training method, complex training maximizes athletes' strength and explosive power performance by organically combining maximum strength training and fast strength training and utilizing the post-activation potentiation effect. Its core lies in the similarity of movement patterns, the fixity of training sequence, and the differentiation of loads, making it suitable for improving event-specific capabilities and optimizing training efficiency in various sports.

2. Unilateral Complex training

Unilateral complex training is a special form of complex training, with its core lying in focusing on the independent work of one limb (unilateral leg) in each training session. After completing maximum strength training through muscle contraction of the limb, it is immediately followed by low-load fast strength training with biomechanical movement patterns similar to those of the high-load resistance training on that side. For example, single-leg squats (maximum strength training) are first performed, followed by single-leg fast jumps (fast strength training). This training method not only inherits the advantages of complex training but also further strengthens the strength, explosive power, stability, and neuromuscular control ability of the unilateral limb. Unilateral complex training is based on the post-activation potentiation (PAP) effect. By activating the neuromuscular system through high-intensity resistance training of the unilateral limb, it enables the limb to generate greater force and speed during subsequent plyometric training. In addition, unilateral training can more directly address issues such as unilateral limb strength deficiencies or asymmetry, thereby improving overall athletic performance. Unilateral complex training is an efficient and targeted training method. By organically combining maximum strength training and fast strength training of the unilateral limb and utilizing the post-activation potentiation effect, it maximizes the improvement of strength, explosive power, stability, and coordination of the unilateral limb. Its core lies in the independence of the unilateral limb, the similarity of movement patterns, and the differentiation of loads. It is suitable for various training objectives, such as improving bilateral strength imbalance, enhancing event-specific athletic performance, strengthening stability and coordination, and rehabilitation and injury prevention.

3. Bilateral Complex training

Bilateral complex training is a basic form of complex training, with its core being the simultaneous muscle contraction of both limbs (both legs or arms) during training. After completing maximum strength training through the coordinated work of bilateral limbs, it is immediately followed by low-load fast strength training with biomechanical movement patterns similar to those of bilateral high-load resistance training. For example, squats (maximum strength training) are first performed, followed by fast two-leg jumps (fast strength training). This training method fully utilizes the synergistic effect of bilateral limbs, aiming to efficiently improve athletes' overall strength, explosive power, and neuromuscular coordination. Bilateral complex training is based on the post-activation potentiation (PAP) effect. By activating the neuromuscular system through high-intensity resistance training of bilateral limbs, it enables both limbs to generate greater force and speed during subsequent plyometric training. In addition, bilateral training can more directly enhance overall strength levels, making it suitable for sports requiring high force output. Bilateral complex training is an efficient and fundamental training method. By organically combining maximum strength training and fast strength training of bilateral limbs and utilizing the post-activation potentiation effect, it maximizes the improvement of strength, explosive power, and neuromuscular coordination of bilateral limbs. Its core lies in the coordination of bilateral limbs, the similarity of movement patterns, and the differentiation of loads. It is suitable for improving overall strength, developing explosive power, strengthening neuromuscular coordination, and serving as an important form of basic strength training.

4. Maximum strength

Maximum strength refers to the highest force value that the body can generate by overcoming external resistance through the maximum voluntary contraction of the neuromuscular system during static or dynamic movements. It is an important manifestation of the body's strength quality, reflecting the maximum force output capacity of muscles under specific conditions. Maximum strength includes not only isometric contraction strength under static conditions but also concentric and eccentric contraction strengths under dynamic conditions. Maximum strength depends on the high activation of the neuromuscular system, the size of muscle cross-sectional area, and the distribution of muscle fiber types. Through methods such as high-intensity resistance training, isometric training, and eccentric training, maximum strength levels can be effectively improved, providing important support for strength-based and explosive sports, as well as rehabilitation and functional training.

5. Explosive power

Explosive power is an important form of rapid strength in the quality of strength, consisting of two core elements: strength and speed. It reflects the ability of muscles to generate maximum acceleration and output maximum power through the rapid release of maximum strength in the shortest time. The performance of explosive power not only depends on the muscle's strength level but also on the efficient coordination and rapid contraction ability of the neuromuscular system. Currently, the concept of explosive power mainly involves the following aspects: maximum power, shortest time, maximum acceleration, and rapid strength. Explosive power relies on the combination of strength and speed, the participation of fast-twitch muscle fibers, the efficient coordination of neuromuscular, and the rapid energy supply capacity of the phosphagen system. Explosive power levels can be effectively improved through plyometric training, high-intensity resistance training, complex training, and event-specific movement training.

6. Changing direction ability

Changing Direction Ability (COD) refers to an athlete's capability to rapidly alter movement speed or direction under predictable directional conditions. It encompasses the complete process of deceleration, direction change, and re-acceleration within a short timeframe, serving as a critical motor quality in numerous sports such as basketball, football, volleyball, and tennis. COD relies not only on an athlete's technical proficiency (e.g., body posture, footwork, arm movements, and braking mechanics) but is also closely associated with acceleration capacity, muscle characteristics (e.g., maximum strength, explosive power, rate of force development, and reactive strength), and neuromuscular coordination. Through technical training, strength and explosive power training, plyometric training, and sport-specific simulation drills, COD can be effectively enhanced, providing essential support for sports that require frequent direction changes, such as basketball, football, and tennis.

7. 1RM squat

1RM squat is an important indicator for evaluating the maximum strength of the lower limbs. Coaches and athletes often rely on the test results of 1RM squat to develop maximum strength training plans, monitor training effectiveness, and assess the physical condition of athletes.

8. Isometric Mid-Thigh Pull

Isometric Mid-Thigh Pull is a multi-joint exercise mainly used to evaluate an athlete's overall body strength and force-generating ability. "Isometric" means that during the movement, the barbell remains stationary. The athlete needs to pull the barbell with maximum force in a specific posture, but the barbell does not move. This test movement can assess athletic qualities such as maximum strength and explosive power, which are crucial for most sports movements. Unilateral Isometric Mid-Thigh Pull (including the left leg and the right leg) is an isometric contraction exercise performed with a single leg, mainly used to evaluate the maximum muscle strength, explosive power, and muscle force-generating characteristics of a single lower limb.

9. Counter-Movement Jump

Counter-Movement Jump is a commonly used test method in the fields of sports science and sports training to evaluate the explosive power of the lower limbs. By measuring the vertical distance from the ground when an athlete takes off to the highest point of the jump, it reflects the magnitude of the explosive power of the lower limbs. Unilateral Counter-Movement Jump is similar to the two-leg CMJ. It measures the vertical distance from the ground when a single leg takes off to the highest point of the jump, thereby reflecting the magnitude of the explosive power of a single leg.

10. Drop Jump

Drop Jump, is a commonly used practice and testing method in sports training and sports performance assessment. It is mainly used to develop and evaluate the explosive power and reactive strength of the lower limbs. Unilateral Drop Jump focuses on the training and assessment of the explosive power and reactive strength of a single leg.

11. Sprint

Sprint refers to a form of exercise where one runs at the fastest speed over a short distance. "5-meter Sprint" and "10-meter Sprint" refer to testing or training activities in which running is completed at the fastest speed within a specific short distance (either 5 meters or 10 meters). These are often used to assess and improve an athlete's short-distance acceleration ability and explosive power.

12. 180º Change of Direction Speed

180-degree change of direction refers to the ability of athletes to quickly and accurately complete a 180-degree change in direction during the course of movement. Coaches will formulate targeted training plans based on the test results of athletes' 180-degree change of direction speed to improve their ability to change directions.

13. Jump-spike speed

Jump - spike speed refers to the speed of the volleyball at the moment when a volleyball player hits the ball during a jump - spike action. An athlete's explosive power, coordination, and flexibility also have an impact on the jump - spike speed. Good explosive power enables athletes to generate greater force in an instant.

14. Jump serve speed

The jump serve is a highly aggressive serving method in volleyball games. By testing the jump serve speed, we can intuitively understand the initial speed given to the volleyball by the athlete during a jump serve and use this to measure the power and aggression of the athlete's serve. The athlete's leg explosive power determines the height of the approach jump and the hitting force.

CHAPTER 2
LITERATURE REVIEW

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Over the past year, this study has utilized international academic journal databases such as the Shanghai University Library, Shanghai Sport University Library, China National Knowledge Infrastructure, Web of Science, Sport discous TM, Google Scholar, Science Direct, and Scopus to conduct unilateral, bilateral, complex, resistance, strength, explosive power, changing direction ability, "Unilateral Training," and "Bilateral Training." Search for relevant literature using keywords such as "Complex Training", "Strength Training", "Exploratory Power", and "changing direction ability". By organizing and refining domestic and foreign literature and books, sufficient theoretical basis and solid theoretical foundation are provided for the writing of this paper.

Research theory

1. Sports adaptation theory

Selye, H believes that adaptation can be divided into three stages: alarm, resistance, and fatigue, and then raises the issue of local adaptation by changing the structure of proteins in certain parts of the body to generate local adaptation. In sports training, it is believed that stressors are generated through load and intensity, and the subsequent changes in stimulation are called adaptation. When athletes are stimulated, they first enter the alarm stage, and their various organ systems increase their working ability. With the continuous stimulation, they enter the resistance stage. At this time, the body will continue to confront the stimulation, gradually improving its own abilities and gradually adapting to changes in the organs and systems of the body. At this time, due to the continuous resistance of the body to stimuli, fatigue will occur, entering the fatigue stage, and the athlete's resistance ability will decrease. If the body continues to resist stimuli at this time, it will cause deterioration of the body (Selye, H. 1956). Coach Kang Xilman proposed in his book "The Science of Swimming" that adaptation should be based on the three stages of adaptation theory proposed by Selye, H which includes hyper adaptation, adaptation, fatigue, and maladaptation. It is believed that different amounts and intensities of training will cause different reactions, and only under a sufficiently large stimulus will the body appear in a new state (Countsilman, E. J. 1968). Neumann proposed a transformation adaptation model, which suggests that the human body first adapts to the nervous system during 7-10 days of training. Within 10-20 days, there is a significant improvement in the body's energy supply system and changes in muscle protein production. Within 20-30 days, the body's energy conversion rate accelerates and recruitment level increases. Within 30-40 days, various organs and systems of the body are significantly improved, and action economy is also optimized. (Neumann, G. 1991)

2. Cross transfer theory

Cross education refers to the improvement in motor performance of the same limb on one side after training or practice. For example, when a team member's right leg is injured and unable to undergo strength training, the strength level of the right leg can also be effectively improved through strength training on the left leg. There are numerous studies on cross transfer training, and a large number of studies have also confirmed that strength training has a clear "bilateral transfer" phenomenon (Ruiyuan, Wang. 2010). Manca, et al. (2017) estimated through meta-analysis that various unilateral resistance training methods can induce an average strength gain of 11.9% for untrained limbs in reverse, while the strength gain through isotonic dynamic training is 15.9%, and the gain through centrifugal training can even reach 17.7%.

Haiye, Qiu (2016) conducted an 8-week, three weekly training intervention on the right upper limb of participants in a study exploring the impact of different intensities of strength training on the strength quality of the opposite limb. After the intervention, test the changes in the strength and fitness of the left upper limb of the subjects. The results showed that in the non-training side of the upper limb strength of the subjects, the improvement in muscle endurance was the greatest, followed by the maximum muscle strength, and finally the explosive force of the muscles, while there was almost no change in muscle circumference.

In recent years, more and more coaches have begun to pay attention to and recognize this phenomenon of cross transfer and have conducted cross training based on it. However, there is no consensus on the neural mechanism of cross transfer phenomenon in resistance training. This transfer theory is more commonly applied in clinical treatment research or research on unilateral limb injuries. Magnus, M. (2013) found that after one arm fracture, intensity strength training on the other non-fractured limb can significantly improve the muscle strength, range of motion, and arm function of the fractured arm. This study has a significant impact on recovery after unilateral injury.

From this, it can be seen that unilateral training is not only a way to choose physical fitness training, but also an effective auxiliary treatment and recovery method for sports rehabilitation.

3. Bilateral limb strength loss phenomenon

During training, it was found that using resistance exercises in a bilateral mode can lead to insufficient bilateral strength. Specifically, when the forces generated by the contraction of each limb muscle are added together, they are often greater than the forces generated by the simultaneous contraction of both limb muscles. This phenomenon is called Bilateral Force Deficit (BFD). Henry first proposed this concept in 1961. Belli et al. (2014) argue that the existence of bilateral force deficit is due to differences in the number of motor units recruited during single and bilateral exercises. Secondly, the muscle coordination of the two modes of practice is also different. During bilateral practice, changes in the nervous system, especially the dispersion of attention, can inhibit the degree of nervous system activation.

Yang, Wang. (2016) found in his experimental research on his doctoral thesis that the phenomenon of bilateral limb force deficit is commonly present in subjects. In his study, he randomly divided the subjects into three groups: a single leg training group, a double leg training group, and a no training group. The single and double leg training groups received training interventions for eight weeks of single leg squatting and double leg squatting, respectively. He found that after eight weeks of experimental intervention, there was a significant difference in bilateral limb ratio (BLR) between the two leg groups, while there was no significant difference in BLR between the single leg group and the no training group before and after the experiment. Short term moderate load squat training can significantly improve bilateral limb strength loss. From this, it can be seen that using unilateral limb exercises in resistance training of the lower limbs can achieve a greater load than bilateral limb exercises and obviously can generate greater stimulation on the target muscle group.

Literature review

1. Research on maximal strength

1.1 Definition of maximal strength

In the book "Sports Training" (2000), it is pointed out that maximal Strength refers to the maximum Strength displayed by a muscle during exercise when overcoming peripheral resistance through maximum voluntary contraction. In current competitive sports, the importance of strength plays a crucial role, and it also plays a fundamental role in the normal performance of skills and tactics. Xingchen, Hou. (2014) believes that maximum Strength refers to the ability of the body to generate maximum Strength during static or dynamic movements and also refers to the maximum Strength displayed by muscles when overcoming peripheral resistance through maximum voluntary contraction during movement. Maximum strength is also an important manifestation of the body's strength and quality, referring to the ability of muscles to contract to overcome external resistance and generate maximum Strength. In training, the high load repetitive training method is usually used to stimulate athletes, effectively improving their maximum strength value. The improvement of maximum strength plays a crucial role in the overall performance of athletes. When selecting the load and method of strength training, it is necessary to make appropriate arrangements based on different projects and daily training loads.

In summary, maximal strength is also an important manifestation of the body's strength and quality, referring to the ability of muscles to contract to overcome external resistance and generate maximum strength. In training, the high load repetitive training method is usually used to stimulate athletes, effectively improving their maximum strength value. The improvement of maximum strength plays a crucial role in the overall performance of athletes. When selecting the load and method of strength training, it is necessary to make appropriate arrangements based on different projects and daily training loads.

1.2 Factors influencing maximal strength

Jianping, Liu. et al. (2000) believed that the maximum strength of muscles plays a different role in different projects. The greater the resistance of muscles against the periphery, the more obvious the effect of maximum strength. The maximum strength can be effectively improved by increasing the weight of the load. Research has shown that when the training load is equal to or greater than 80% RM, there is a significant increase in muscle tension, thereby enhancing the parameter value of maximum strength. Maximizing muscle strength training can significantly improve the overall muscle work ability of the body. Some sports require athletes to have both lighter weight and greater strength. Therefore, athletes are required to have relatively high absolute strength during training.

In "Modern Coach Scientific Training Theory and Practice" (2012), it is explicitly stated that the maximum strength is the maximum ability exhibited by human skeletal muscles during the period of maximum voluntary contraction. The main reason for its improvement is the continuous improvement of the nervous system combined with the continuous enhancement of muscle fiber cells. Meanwhile, Zaziolsky, M. (2011) argued in his experimental research that the body can be static or dynamic during the process of generating absolute force. He believed that the maximum strength generated by a muscle or muscle tissue group is the absolute maximum strength (AMS) of the human body.

Xiong, Wang. and Zhaozhe, Shen (2014) also believed in their training research that the ability of a muscle or muscle group to overcome peripheral resistance, when the control of the nervous system and the participation of all the fibers in the body, is the maximum strength value. The increase in maximum strength is mainly positively correlated with the weight of the load overcome by the body during exercise. When the load of peripheral resistance increases, the contraction ability of muscles will also increase. They believe that when the peripheral resistance load is higher than 80% RM, it can effectively increase the participation of more muscles.

Brown, Lee. E (2007) discussed in his book that when you find that no training can improve your training performance, then you should increase your strength. Generally, high load training methods are used to stimulate maximum strength growth, and the training load during training is controlled between 85-95% 1RM. Some researchers have suggested that the training load control should not be lower than 80% 1RM. The specific training load and frequency should be controlled according to the athlete's own training. Generally, the number of training sessions per week should be controlled between 2-4, and the number of training groups should be controlled as much as possible between 4-6. The interval time between each group should be 2-3 minutes.

In resistance training, there is a dose-response relationship between training load and muscle strength growth. The increase in muscle strength will be most significant at a certain training load parameter variable point, and excessive resistance training load can easily cause stress damage; If the resistance training load is too low, it is difficult to achieve the desired effect (Bei, Wang. 2013). The factors that affect muscle strength include training load, training volume, training movements, exercise sequence, inter group rest, and movement amplitude, as well as an important factor that is often overlooked - movement speed (Griffin, S. 2005). A study (Tanimoto, M. 2008) has shown that even low-intensity resistance training below 65% 1RM during the centripetal and centrifugal contraction stages of LST training for 3 seconds each may lead to an increase in muscle strength, consistent with the effect of HN. This indicates that prolonging the action speed during the centripetal and centrifugal processes that generate sustained tension is beneficial for increasing maximum strength

From the perspective of the factors that produce the best results in maximum strength training, Lyons, M (2022) found that doing a slow repetition at an 85% RM load intensity can maximize muscle tension throughout the entire range of motion, leading to greater strength gain.

1.3 Physiological principles of maximum strength

Maximum strength refers to the maximum force that the neuromuscular system can generate during maximum voluntary contraction (Bompa, T. O. B., 2018). The physiological factors influencing maximum strength performance are as follows: Physiological cross-sectional area of skeletal muscle: Under normal circumstances, the physiological cross-sectional area of skeletal muscle is positively correlated with maximum muscle strength. Tendon stiffness: Increased tendon stiffness facilitates the transmission of force from muscles to bones, thereby enhancing maximum muscle strength performance (Kubo, K. 2006). This may reduce force loss during contraction. Proportion of fast-twitch muscle fibers: Compared with slow-twitch muscle fibers, fast-twitch muscle fibers have larger diameters and more contractile proteins, and they exhibit greater force during contraction. Therefore, individuals with a higher proportion of fast-twitch muscle fibers can demonstrate higher maximum strength. Motor unit recruitment ability: When resisting greater resistance, the human body requires more muscle fibers to participate in contraction. At this time, the ability of the central nervous system to recruit high-excitability threshold motor units affects an athlete's maximum strength performance. Firing frequency of α-motor neurons: After motor unit recruitment, the firing frequency of action potentials by α-motor neurons can alter the force generation characteristics (Suchomel, T. J. 2018), i.e., maximum muscle strength performance. When the action potential firing frequency of motor units increases from the minimum to the maximum value, the force magnitude may increase by 300–1500% (Enoka, R. M. 1995). Coordination ability of the central nervous system among different muscle groups: During rapid muscle contraction, the human body needs to coordinate multiple muscles to complete movements. By ensuring the simultaneous contraction of agonist muscles, synergistic muscles, and fixator muscles, and coordinating their contraction at the same node, higher maximum strength can be exerted. In addition to the above factors, physiological factors such as reduced neuromuscular inhibition and the degree of synchronous excitation of relevant muscle centers may also affect maximum muscle strength performance. However, compared with maximum muscle strength performance, reduced neuromuscular inhibition and the degree of synchronous excitation of relevant muscle centers (Semmler, J. G. 2002) are more closely related to the rate of force development. In summary, the physiological factors influencing maximum muscle strength performance include: physiological cross-sectional area of skeletal muscle, tendon stiffness, proportion of fast-twitch muscle fibers, motor unit recruitment ability, firing frequency of α-motor neuron action potentials, coordination ability of the central nervous system among different muscle groups, reduced neuromuscular inhibition, and the degree of synchronous excitation of relevant muscle centers.

1.4 Lower-limb maximum strength test indicators and methods

Xingyue, Liang (2023) mentioned in the research on the impact of lower-limb explosive power of college students majoring in basketball that the maximum repetition number of squats (squat 1RM) is a golden indicator reflecting the maximum lower-limb strength, which examines the strength of the subject's lower-limb muscle groups such as the quadriceps femoris, gluteus maximus, and hamstrings. The test method is cited from the research of the National Strength and Conditioning Association (NSCA) and others. Yanjia, Shao (2015)The detection methods of maximum muscle strength generally include bench press, deadlift, squat, etc. Dynamic peak force can be measured using a one-repetition maximum (1RM) squat, that is, the 1RM squat. And the Isometric Mid-thigh Pull (IMTP) can be used to measure the peak force of isometric extension of the lower limbs during the isometric test. Comfort, P (2015) showed in the research that there is a high correlation between the IMTP peak force and both the maximum squat strength and explosive power.

In conclusion, combined with the expert questionnaire, this study finally determines that 1RM squat and Isometric Mid-Thigh Pull (Unilateral and Bilateral) are selected as the test indicators for the maximum strength of volleyball players. In addition, since the load intensity of the intervention training in this study requires a reference basis, the 1RM tests of half-squat and deadlift for the athletes in the bilateral group are added in the pre-test, and the 1RM tests of Bulgarian split squat, single-leg half-squat, and single-leg deadlift for the athletes in the unilateral group are also added. The specific test methods are as follows:

1)1RM squat

Test for the squat 1RM test, considering safety, the squat is performed on a Smith machine with a fixed trajectory. The test standard follows the 1RM lower-limb test standard recommended by the NSCA (National Strength and Conditioning Association). The method of increasing the weight for the maximum squat strength is adjusted according to the athlete's incremental load capacity. The specific process is as follows: After the subject warms up, perform a weight-bearing squat with a relatively small load for 5-10 easy repetitions. After a one-minute rest, increase the weight by 5%-10% (for 3-5 repetitions). After a two-minute rest, increase the load by 5%-10% (for 2-3 repetitions). After a three-minute rest, with protection, the subject attempts to complete one standard weight-bearing squat. If successful, rest for three minutes, increase the load and attempt another lift to obtain the 1RM squat weight. The test methods for Bulgarian split squat, half - squat (both unilateral and bilateral legs), and deadlift (both unilateral and bilateral legs) are the same as those for the 1RM squat test. The specific movement requirements are as follows:

Squat movement requirements: The subject stands with feet shoulder - width apart, slightly wider than the shoulders, and the toes slightly externally rotated. One squat movement is as follows: Place the barbell behind the neck, initiate the squat by flexing the hips, squat down until the thighs are parallel to the ground, and then fully extend the three joints of the lower limbs to an upright position.

Bulgarian split squat movement requirements: The subject lowers both the front and rear legs until the angle between the thigh and calf of each leg is 90 degrees, and the calf of the rear leg is parallel to the ground. The upper body leans slightly forward, with the feet shoulder-width apart, and the knees and toes are in the same direction.

Half squat movement requirements: Stand with the feet shoulder-width apart or slightly wider than the shoulders and turn the toes slightly outward. Place the barbell on the trapezius muscle at the back of the neck, keep the back straight, and tighten the core. Slowly squat down until the thighs are approximately at a 45-degree angle to the ground (the half squat position). Pay attention not to let the knees go beyond the toes, and then use the strength of the legs and hips to push the body up and return to the starting position.

Deadlift movement requirements: Grasp the barbell with an overhand closed grip. Keep the barbell close to the shins. Push the feet against the ground, and simultaneously exert force by extending the hips and knees. The barbell rises along a vertical trajectory close to the body. Keep the torso completely upright, retract the scapulae, and fully extend the knees and hips.

2) Isometric Mid-Pull (unilateral and bilateral)

Before the test, all subjects are required to perform trial pulls with 50% and 70% of their 1RM strength. In the formal test, two effective isometric mid-thigh pull tests are conducted on the unilateral and bilateral sides in sequence, with a 3-minute interval between each attempt. Requirements: The subjects should stand with their feet shoulder-width apart. Place the barbell at the position of the second pull in the power clean, with the middle of the thighs firmly against the bar. The subjects should wear weightlifting belts on their hands and fix them to the bar. The hip joint angle should be between 140° and 150°, and the knee joint angle should be between 125° and 145°. For the unilateral isometric mid-thigh pull, the subject stands on one foot, with the non-supporting thigh parallel to and close to the supporting thigh, and the knee of the non-supporting leg bent backward at a 90° angle. Other test details are the same as those for the bilateral test. After the start command is given, the subjects should exert maximum force continuously for 5 seconds. During the test, verbal prompts should be given to the subjects. Record the peak force exerted. The data of the subjects during the test are collected through a force plate (Force plate, Winterthur, Swiss) and Mars software.

2. Research on explosive power

2.1 Definition of explosive power

According to the different characteristics of strength, strength can be divided into maximum strength, rapid strength, and strength endurance, among which rapid strength is the explosive power that this article will talk about (Maijiu, Tian. 2000). Explosive force refers to the maximum work done in a short period of time, which is the product of speed and force. Hui, Zhang. et al. (2004) pointed out in their article that explosive power refers to the maximum amount of work done in a short period of time. Explosive force, as an important manifestation of rapid strength, is characterized by the elongation of muscle fibers during exercise, which increases the contraction amplitude while rapidly increasing the contraction rate, thereby increasing the gradient of muscle tension time. It can also be regarded as instantaneous explosive force. Qing, Wang (2004) believes from the perspective of sports training that explosive force is the force generated by muscle contraction when overcoming peripheral resistance in a very short period of time. He believes that during the process of exercise, the muscles of the human body are coordinated and controlled with each other. In his study on explosive power, Yuping, Fu. (2005) believed that explosive power is the work done when overcoming peripheral resistance. When overcoming peripheral resistance, the body can effectively mobilize more units of movement to coordinate and participate in sports, thereby improving the parameters of explosive power. Maijiu, Tian. (2012) believes that explosive force refers to the ability of a muscle whose tension has already begun to increase to overcome resistance at the fastest speed. Ruiyuan, Wang. (2012) defined explosive force as the ability of muscles to exert strength in a short period of time in Sports Physiology. Explosive power plays a decisive role in many sports, as it is the ability of the body to quickly exert force against resistance, such as shooting in football and dunking in badminton. If there is no explosive power, many athletes will have no competitiveness, and many sports will also lose their ornamental value.

There are also many definitions of explosive power quality by foreign scholars. German researchers such as Bieler et al. (2010) believe that explosive power is a manifestation of rapid strength, which refers to the ability of muscles that have started to increase tension to further improve and develop muscle strength levels at the fastest acceleration. The American Physical Fitness Association (2019) defines muscle burst as the speed at which muscles generate force within a certain range of motion (burst=force x velocity).

In summary, based on the induction and summary of power quality by various researchers, it can be concluded that explosive power is closely related to speed, strength, time, and power. Therefore, the author believes that explosive power is a manifestation of rapid strength and a key indicator reflecting the output power of athletes. It is the ability of the human body's muscles to overcome or counter resistance with maximum strength and speed during exercise.

2.2 Factors influencing explosive power

In the book "Sports Training" (2003), a scientific and systematic evaluation method for explosive power calculation was pointed out. It was mentioned that athletes should do their best and try their best to complete explosive power training as quickly as possible in a short time. Therefore, the parameter of explosive power is an indicator for evaluating rapid strength. The index of explosive power=maximum force/duration of exertion. From this formula, we can calculate the parameters that can increase explosive power by shortening the force application time (while maintaining or increasing the maximum force). Alternatively, while enhancing maximum power (while keeping time constant or shortening usage time), explosive power parameters can also be increased. At the same time, the load and control of explosive training were also determined in the textbook. (1) Load intensity: In the process of developing explosive power, the control of training load intensity is set according to one's own needs. (2) Number of training groups: When arranging training frequency and number of groups, it is necessary to plan reasonably and ensure the speed of completing actions during the training process, while also requiring high involvement of the nervous system. The number of training groups and the number of training sessions per group are not necessarily better. The frequency of repetition is directly related to the intensity of the load. When the training load is heavy and intense, the frequency of repetition should be reduced; When the training load intensity is low, the frequency of repeated training can be increased, usually controlled between 2-5 times. (3) Intermittent time: During the training process, it is necessary to ensure the interval control between groups to ensure that the athlete's training ability returns to its original level. However, the interval time should not be too long. Otherwise, in the next group of training, the control of the nervous system over the muscles will decrease, and the coordination between muscle tissues will be poor, resulting in a decrease in training quality. Reasonably arrange inter group rest time according to the athlete's own recovery ability during the training process. At the same time, simple relaxation exercises can also be done during intervals to accelerate physical recovery and shorten necessary rest time.

Research has shown that using different training loads can lead to different training adaptations, and further indicates the adaptability of specific loads and speeds in muscle strength development (Greg, Haff. 2016). But this does not mean that athletes who require high explosive performance do not need to increase their maximum strength level, as the maximum strength level and the rate of force generation are interrelated (Dragan, M. 2004). Actions related to speed or explosive power often start from a stationary or slow state, and the maximum strength obtained from training can be directly used to generate explosive power (Burke, L.M. 2010).

As mentioned in the previous text, under the condition of constant quality, greater force will produce greater acceleration. But in fact, many sports or technical movements do not have enough time to generate maximum strength. Specifically, the time required to generate maximum force is at least 300 milliseconds; However, the duration of force application in sports skills such as sprinting, jumping, and throwing is approximately 30-200 milliseconds (Christopher, Taber. 2004). Among these sports skills, the ability to quickly generate strength may be more important for competitive athletes. Researchers have conducted extensive research on the relationship between force and velocity. As a well-known basic characteristic of muscle tissue, the force velocity relationship simply expresses the relationship between muscle contraction rate and force generation (Kawamori, N. 2004). For example, during the 1RM squat, the movement speed is particularly slow; When performing vertical jumps and reaching high, because the resistance that the body needs to overcome is relatively small compared to 1RM squats, the speed of the takeoff action is faster than that of the squat action.

Baocheng, Wang; Chuan, Wang. et al. (2003) pointed out in their research training that explosive power is mainly supplied through the ATP-CP system during the training process, and the recovery time of the ATP system is 2-3 minutes. Therefore, it is necessary to reasonably control the interval time between groups during the training process, generally controlled within 2-3 minutes.

Given that athletes need to quickly generate energy in a short period of time, training is needed to unleash greater force in a shorter period of time to generate stronger explosive power. The ability to generate maximum power is an important influencing factor in generating explosive power. The Rate of Force Development (RFD) describes the rate at which a force is generated, which is obtained by dividing the change in force by the change in time (Aagaard, Per. 2002). The increase in the rate of force generation means that athletes have an improved ability to generate internal forces at the same time, and will have an advantage in activities where they do not have enough time to exert their maximum strength.

In previous articles on precautions for explosive training, it was mentioned that training with high load weight is more effective than training with low or medium load. The main reason for this is that during high load training, the body can drive more nervous systems to participate in movement, thereby allowing muscles to gain greater strength. Based on the above points, it can be concluded that in explosive training, heavy loads are usually used as the main approach (Fei, Wang. 2014).

Based on previous research, this study believes that explosive power essentially belongs to the category of power quality, and any factor that affects power quality will affect maximum power and explosive power. Sports training studies categorize the biological factors that affect strength and fitness into the following categories: 1) Mobilization of sports units. 2) The initial length of muscle fiber contraction. 3) Muscle cross-sectional area. 4) Muscle fiber type. 5) The synchronicity of motor unit activation. 6) The coordination of muscle work. 7) The functional state of the nervous system.

2.3 Research on training methods for lower limb explosive power

The explosive power of the lower limbs of athletes, as one of the essential qualities in most competitive sports, has always been the focus of coaches and physical trainers, and various training methods and means have been tried to safely and effectively enhance the explosive power of the lower limbs of athletes, improve sports performance and performance.

Xiaofei, Xia (2017) divided 24 adolescent football players into an experimental group and a control group for an 8-week intervention experiment. The experimental group received an additional 2 lower limb centrifugal training sessions per week. The results showed that the experimental group had a significant improvement in the three indicators related to lower limb explosive power, including standing long jump, standing vertical jump, and right foot vertical jump, compared to the control group.

Ning, Zhang (2019) studied the changes in lower limb explosive power after overload squat training on high school male basketball players. After 8 weeks of training, the subjects were divided into two groups: one group received overload squat training intervention, and the other group received traditional squat training intervention. The evaluation indicators are half squat vertical jump, standing long jump, 15m * 3 turn around run, and 30m acceleration run. By analyzing and comparing the data of two groups of subjects before and after the experiment, the analysis shows that both overloaded squats and traditional squats for 8 weeks can improve the explosive power of the athlete's lower limbs. In the specialized improvement stage, the effect of overload squat training is better than traditional squat training.

In a study conducted by Shaosong, Li (2019) on subjects for 6 weeks, it was found that under a load of 80% RM, single leg flexion leg hard pull training was more effective than double leg flexion leg hard pull training. After a 6-week intervention experiment, the lower limb explosive force test indicators showed that single leg approach, standing long jump, 60 ° knee extension torque, and 1 RM leg flexion hard pull. The single leg hard pull experimental group showed a more significant improvement than the double leg hard pull control group, Single leg training is more conducive to the development of lower limb explosive power than double leg training.

Yimeng, Huang (2020) found that after intervention, the composite training group showed the most significant improvement in indicators related to basketball performance, such as standing jump, approach jump, 10yd sprint, maximum strength of lower limbs, and force measurement table, by comparing the effects of high-weight resistance training, ultra long training, and composite training on lower limb explosive power of basketball athletes in sports colleges.

Zhaoqing, Li (2021) also found that after 8 weeks of single leg and double leg super isometric training on 20 college basketball athletes, single leg super isometric training had a more significant impact on the explosive power of the lower limbs than double leg super isometric training.

Qinbao, Lu (2021) compared and explored the effects of functional training and traditional resistance training on lower limb explosive power in 20 high school basketball players. After the 8-week experimental intervention, the results showed that both training methods had a significant effect on improving lower limb explosive power, but the degree of functional training improvement was more significant. The functional training experimental group showed a greater improvement in performance in the tests of standing long jump, squat jump touch height, swing arm CMJ touch height, and step up run touch height indicators than the control group of traditional resistance training.

From the above research, it can be seen that there are currently various training methods and techniques that have a significant effect on improving the explosive power of athletes' lower limbs. With the advancement of science and technology and the emergence of new equipment, many scholars have begun to explore the use of new equipment to develop the explosive power of athletes' lower limbs.

Qinghai, Zhao (2020) divided 36 subjects into three groups, with Group A and Group B as experimental groups. They received single leg load resistance vibration training and double leg load resistance vibration training on the Powerplate vibration table, respectively. Group C was the control group, and ordinary double leg load resistance training was conducted on a flat training ground. The results showed that the lower limb explosive force related test indicators of the three groups, CMJ, standing long jump, and 30 meter run, all improved. However, the improvement effect of experimental groups A and B was significantly greater than that of the control group C.

Kaibin, Cao (2017) compared the effects of three instruments on the development of lower limb explosive power using barbell, Keiser air resistance training device, and Cormax end explosive power release device. 18 participants were randomly divided into 3 groups and underwent 8 weeks of 50% 1RM deep squat training using Keiser air resistance training equipment, Cormax end explosive force release equipment, and barbell, respectively. The final results of SJ (squat jump), CMJ (reverse jump), four consecutive jumps, and isokinetic muscle strength tests showed that the training effects of the Cormax end explosive force release device and Keiser air resistance training device were significantly better than those of barbell squat training. At the same time, for explosive training, the training effect of the Cormax end explosive release device is better than that of the Keiser air resistance training device.

In summary, training methods such as centrifugal resistance training, single leg resistance training, super isometric training, compound training, functional training, and the use of new equipment can have a positive impact on the improvement of lower limb explosive power, helping athletes improve their lower limb explosive power and improve their sports performance and performance. In China's training practice, most of the training for lower limb explosive strength still focuses on heavy weight anti load training such as barbell squats. Research has shown that barbell squats can improve the explosive power of the lower limbs to a certain extent, but there are also safety hazards. Using weight training to improve one's explosive power is not the optimal choice

2.4 Research on volleyball athlete's explosive power training

Nowadays, competitive volleyball has placed physical fitness training in an important position in training work. Comprehensiveness, height, speed, and versatility are the basic requirements for volleyball players, especially men's volleyball players, who need to have a certain level of height on the field. Therefore, increasing the jumping height as much as possible for male volleyball players with a certain height has an indescribable effect on training and competition. In the physical training of volleyball players, lower limb explosive strength training plays a very important role, especially in specialized technical movements such as blocking, spiking, and jumping serve. Relying on the strong explosive strength of the lower limbs to provide a high bounce height for the performance of specialized technical movements is of great significance. For volleyball players, qualities such as speed, strength, agility, flexibility, and endurance are essential. Any application of techniques and tactics on the volleyball field is achieved through good physical fitness. Therefore, in recent years, more and more physical training methods have been applied to the daily training of volleyball athletes, such as resistance training, rapid stretching and complex training, core strength training, etc. In recent years, the training of volleyball players' explosive power has received increasing attention from coaches and researchers. Explosive power is a manifestation of rapid power and a key indicator reflecting the output power of athletes. Volleyball players' specialized technical movements such as bouncing, spiking, and jumping serve on the field cannot be separated from the display of explosive power. Therefore, competitive volleyball now places the training of volleyball players' explosive power in an important strategic position. The concept of "one inch tall, one inch strong" is vividly reflected in volleyball events. How to more scientifically and efficiently carry out explosive training for volleyball players has become a focus of attention for coaches and researchers. In the past, the explosive training of volleyball players was mostly carried out through multiple sets and multiple rounds of ultra long training, which carried a certain load. Such training often leads to severe knee joint wear and premature injury in most volleyball players. Therefore, the training principle of "high intensity, few repetitions" has been proposed by many scholars, in order to improve the efficiency of training and combine muscle strength and movement speed training for the explosive strength training of upper and lower limbs of volleyball athletes.

2.5 Lower-limb explosive power test indicators and methods

Yongqiang, Yang (2022) mentioned that the Counter Movement Jump (CMJ) is a simple, practical, effective, and highly reliable method for measuring lower-limb strength. It has become one of the routine test items for athletes conducted by many physical fitness coaches and sports scientists. Xingyue, Liang (2023), in the research on the impact of lower-limb explosive power of college students majoring in basketball, adopted indicators such as the Counter Movement Jump (CMJ), vertical jump with arm swing, Squat Jump, standing long jump, and 10-meter sprint. Xin, Miao (2010) stated in the article that many relevant studies at home and abroad have selected vertical jump and standing long jump to evaluate the level of lower-limb rapid strength. This study also selects these two indicators to evaluate the improvement of the overall lower-limb rapid strength by two different training methods. The CMJ test is a basic method for vertical jump ability testing. An example of the plyometric peak force is the maximum ground-reaction force generated by an athlete during a Counter Movement Jump (CMJ), and the CMJ belongs to the plyometric movement of muscles. The research by Klavora et al. (2013) shows that the CMJ can be used to measure the lower-limb explosive power of athletes and can serve as an effective tool for measuring and monitoring lower-limb sports performance. Markovic, G (2017), in the research on the explosive power of 93 physical education students, selected the Drop Jump (DJ) and the Counter Movement Jump (CMJ) tests to explore the influencing factors of explosive power. The research indicates that the DJ can be used to measure the lower-limb explosive power of athletes and has a reliable correlation. Tao, Guan (2024) also mentioned in his article that the Drop Jump (DJ) and the Counter Movement Jump (CMJ) were used to measure explosive power. Regarding speed-explosive power, Xinghua, Huo (2014) used 5-meter, 10-meter, and 30-meter sprints to conduct tests in the comparative study of single-leg and double-leg explosive power exercises. Regarding the special explosive-power performance ability of volleyball players, Zhuang, Wang (2024), in the comparative study on the impact of unilateral limb resistance training on the jumping quality of college volleyball-major students, used jump-serve and jump-spike to measure the special explosive - power performance ability of volleyball players. In conclusion, combined with the expert questionnaire, this study finally determines Counter - Movement Jump, Drop Jump, Sprint, Jump - spike speed, and Jump - serve speed as the measurement indicators for explosive power. The specific test methods are as follows:

1) Counter-Movement Jump (unilateral and bilateral)

Movement requirements: The subject should stand with feet shoulder - width apart, toes slightly turned outwards, and place both hands on the hips to avoid using arm swing for force. In the unilateral counter - movement jump test, the tester asks the subject to complete the jumps using one side as the supporting side in turn. The non - supporting thigh should be parallel to the supporting thigh, with the knee joint flexed at 90 degrees. In the counter - movement jump test, the subject should quickly flex to lower the center of gravity. When the knees are bent at approximately 90 degrees, rapidly extend the three joints of the lower limbs to jump upwards. The subject is required to complete the jumps with maximum effort. For both the unilateral and bilateral counter - movement jumps, each movement is tested twice, with an interval of 45 seconds. The best jump height is recorded. The jump height data of the subjects during the test are collected using a three - dimensional force plate (Force plate, Winterthur, Swiss) and Mars software.

2) Drop Jump (unilateral and bilateral)

Movement Requirements: The height for the unilateral drop jump is 15 cm, and for the bilateral drop jump is 30 cm. The subject stands on a 15 - cm or 30 - cm plyometric box, drops freely, lands on the force plate with one foot (for unilateral) or both feet (for bilateral) simultaneously, and then jumps up with full force in the shortest possible time. A ground contact time of ≤ 250 ms is regarded as a valid test. During the take - off, the three joints of the lower limbs should be fully extended. Before the test, all subjects need to do trial jumps with 50% and 70% of their maximum intensity. During the formal test, they conduct 2 valid tests in the order of the name list, with an interval of about 45 seconds between each test. Record the RSI (m/s) and the best result. The data of the subjects during the test are collected using a force plate (Force plate, Winterthur, Swiss) and Mars software.

3) Sprint (5m and 10m)

The testing methods for subjects in the unilateral complex training group and the bilateral complex training group are the same. The Smartspeed split - timing system (Smartspeed, Fusion Sport, Australia) is used to record the results at the 5 - meter mark and the 10 - meter finish line respectively. The light - beam gates, which are 70 cm in height, are deployed at the starting point and the finish line. Requirements: The athletes start the sprint test in a standing position, with the designated front foot placed behind the starting line. Then they accelerate forward with maximum effort until they pass through the last pair of photoelectric gates. Each athlete conducts two tests, and the best result is taken, with an interval of 2 minutes.

4) Jump-serve speed test

Use a radar speed gun (Velocity speed gun, Bushnell, USA) to collect the Jump-service speed data. The subjects are required to complete the ball - speed test by performing an overhand jump - serve. The hitting area measures 1.5m×1.5m, and the serving distance to the target hitting area is 4m. It is required that the ball - tosser and the server remain the same throughout the two tests.As shown in Figure 2.

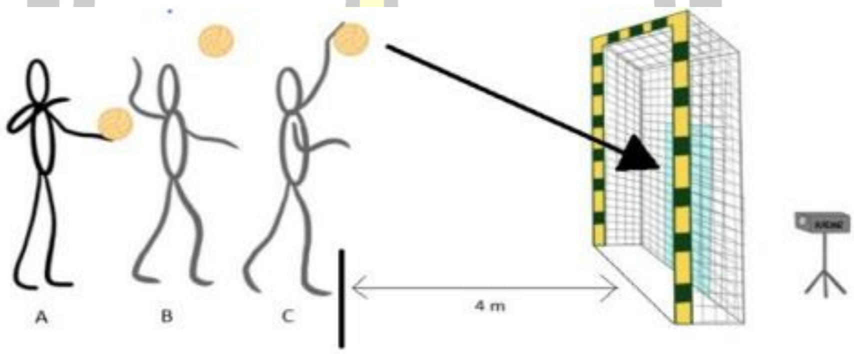

Figure 2 Jump-serve speed test

5) Jump-spike speed test

The velocity data of jump - spiked balls are collected using a radar speed gun (Velocity speed gun, Bushnell, USA). The subjects are required to hit a standard volleyball with maximum force in a straight line towards the opposite court within the designated area. The height of the net is 2.43m. At the same position near the net, the same team member is responsible for passing the ball. The passing position is 1.5m in front of the net and 5m away from the spiker. Each subject has 3 test opportunities, with an interval of 30 seconds between each attempt.As shown in Figure 3.

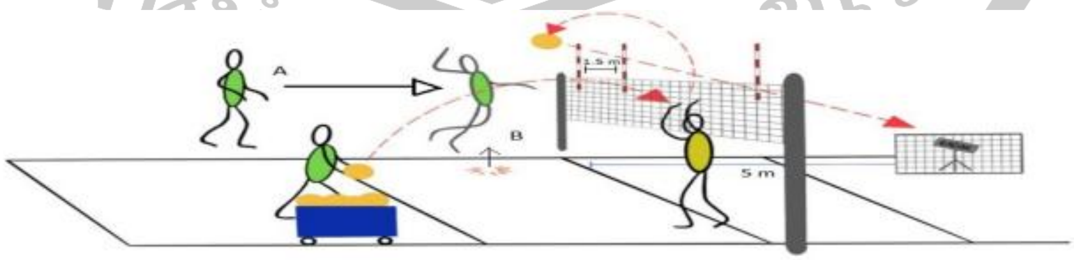

Figure 3 Jump-spike speed test

3. Research on changing direction ability

3.1 Definition of changing direction ability

Mobile ability is a physical fitness that the vast majority of athletes must possess during the exercise process, and in recent years, physical fitness has become very prominent in various sports, and even an important factor leading to competition results. Yang, Lin (2014) pointed out that the ability to move quickly should become an important physical fitness for tennis athletes.

Hansheng, Huang (2001) regarded movement as an ability, which refers to the positional changes that occur between the starting point and the end of braking. It represents the ability of athletes to complete movements in the least amount of time. Later, Qing, Meng (2010) defined mobility as the ability of an athlete to react to various movements and complete a certain action in the shortest possible time during exercise. The changing direction ability refers to the ability of athletes to accurately, quickly, and harmoniously change their body direction under constantly changing scenes. Jianmin, Wang (2006) proposed that mobility refers to the specialized qualities of athletes. Athletes are able to constantly adapt to changes on the field of play, allowing them to accurately predict the position of the ball and quickly move to the predetermined position. Therefore, in actual training, the practice of mobility must be arranged in conjunction with the specific characteristics of athletes.

Many scholars directly believe that the ability to change direction and move is a sensitive quality, but in fact, the concepts of the two are both interrelated and different. Sensitivity can have an impact on the ability to change direction and move, but it is only one aspect of it. The better an athlete's ability to change direction and move, the higher their requirements in terms of explosive power, reaction ability, and body sensitivity; However, excellent directional mobility, strong explosive power, and fast speed of athletes do not necessarily mean that their sensitivity is better, as athlete sensitivity involves various influencing factors such as nervous system control (Sheppard, J.M; Young, W.B.2006).

Lei Li (2013) proposed in her thesis that 20 female experimental subjects were randomly divided into an experimental group and a control group, and statistical comparative analysis was conducted on 5 mobility related indicators before and after intervention. The discovery of training methods that apply core strength can effectively improve the athlete's ability to move quickly and change direction.

Baechle (2008) and Draper et al. (1985) argued that agility encompasses rapid movement throughout the body and the ability to change direction during movement. Moreno (1995) summarized "speed" as a multi plane, multi-directional technical action, integrating acceleration, explosive action, and reactive action. From a mechanical perspective, sensitivity is reflected in changes in the body's center of gravity; From the perspective of information acquisition, sensitivity requires the human body to quickly respond to external stimuli with its limbs; Based on the perspective of muscle strength and physical fitness, individual specific techniques and training backgrounds may lead to differential sensitive performance. Sheppard and Young et al. (Hartman, K; Tuneman, P.1986) classified sensitivity as cognitive response ability and directional ability. Pandorf, C.E (2003) argued that without external stimuli, completing a pre-set test route cannot effectively assess sensitivity, emphasizing the importance of cognitive response ability. Tim et al. (Gabbett, Tim. J. 2008) pointed out that responsiveness tests can distinguish athletes of different athletic levels, highlighting the importance of cognitive responsiveness in sports performance. Sensitivity is defined as the ability of the body to quickly change direction or speed in response to external stimuli. Sensitivity includes three parts: perception, decision-making, and direction change (Sheppard, J. M. 2006).

Sheppard and Young believe that the ability to change direction is the ability of athletes to quickly change their speed and direction of movement under predetermined conditions. It includes a short period of deceleration, direction change, and re acceleration. The difference between agility and change of direction ability lies in whether to undergo pre existing external stimuli and cognitive responses. Change of direction ability, as a subordinate ability of agility, does not require a response to external stimuli and is a pre programmed action process.

In summary, the changing direction ability refers to the ability of athletes to quickly and accurately complete corresponding movements in the shortest possible time in different scenarios, which is particularly important in the vast majority of sports. When arranging training, it is necessary to combine the characteristics of the specific event. In addition, the ability to change direction and move is influenced by various factors, and core strength is an important aspect. The prominent performance of movement is sudden change of direction and sudden stop, and the core area is the central link between the upper and lower limbs of the human body. So strengthening the ability of athletes to control their body center of gravity is very helpful for improving their changing direction ability.

3.2 Factors affecting changing direction ability

3.2.1 Maximum leg strength

Swinton, et al. (Lloyd, Ray, Swinton, et al. 2014) reported a strong correlation (r-0.72) between 505 test scores and maximum squat strength scores. Wisl ø ff et al. (2004) reported that there is a very perfect correlation between the absolute strength of a national football player's squat load and their 10m sprint (r=-0.94), 30m sprint (r=-0.71), 10m turn back run (r=-0.86), and vertical jump height (r=-0.87). Leg strength is one of the important factors affecting directional performance. Locke et al. (Locke; Robert, G; Post. et al. 2019) investigated the relationship between maximum isometric force, relative isometric force, and steering ability, and found that absolute force in lower limb isometric lifting was weakly correlated with the 505 test (r=-0.15-0.25), 505 steering deficit test (r=-0.15-0.3), and Illinois test (r=-0.3). However, relative force in lower limb isometric lifting was weakly correlated with the 505 test (r=-0.50-0.54) and Illinois test (r=-0.63) It is highly correlated, and compared to the absolute force of equal length pullers, the relative force of equal length pullers is more closely related to their directional ability. Spiteri et al. (Spiteri, T; Cochrane, J, L; Hart, N. H. et al., 2013) divided 24 participants into strong and weak groups based on lower limb strength levels. The test included the process of 6m sprint, support conversion, and 2.5m sprint movements. They pointed out that the group with stronger strength had higher ground reaction force and impact force during the braking and re acceleration stages than the group with weaker strength.

Spiteri,T. et al. (Spiteri, T. et al., 2014) reported that the level of back squat centrifugal force is highly correlated with 505 test and T-score (r=-0.79-0.89), and centrifugal force can serve as a predictive factor for directional performance. Centrifugal force has a decisive impact on directional ability. Fajardo, Tous. et al. (2016) randomly divided 24 football players into a centrifugal vibration training group and a conventional training group, and the results showed that the centrifugal vibration training group significantly improved V-shaped entry performance. The approaching speed of an athlete before entering is one of the determining factors affecting their directional performance. Rapid reduction of approaching speed is closely related to the athlete's centrifugal force and body posture control ability. Improving leg centrifugal force and body posture control ability can ensure a high approaching speed, and having high centrifugal force and body posture control ability can quickly reduce approaching speed to complete deceleration and braking.

In summary, there are numerous testing indicators for directional ability, and the selection of directional testing indicators can lead to differences in the correlation coefficient results between leg strength and changing direction ability. However, many research results indicate that the maximum strength and centrifugal force of leg muscles are closely related to changing direction ability, and the maximum strength and centrifugal force of legs are important factors affecting changing direction ability.

3.2.2 Legs explosive power

Explosive force refers to the rapid contraction of muscles in a short period of time to output maximum force. Sheppard et al. (2006) pointed out in their study on leg muscle strength models that constitute directional ability that explosive force is one of the important muscle strength factors affecting changing direction ability.

Naruhiro et al. (2008) investigated the relationship between leg explosiveness and changing direction ability in a group of rugby players, and found a moderate correlation (r=-0.42) between reverse jumping and 5m turn back performance. Vescovi et al. (2008) reported a moderate to high correlation (r=-0.47-0.69) between female athlete group reverse jumping and Illinois and Pro agility scores. Castillo, Rodríguez. et al. (2012) pointed out that reverse jumping is highly correlated with 180 ° directional performance (r=-0.6), and reverse jumping height can serve as a predictive factor for left 180 ° directional performance (R^2= 0.46, P<0.01). The above research results indicate a moderate to high correlation between reverse jumping and changing direction ability.

Naruhiro, et al. (2008) evaluated the peak explosive power and relative peak explosive power of the lower limbs using a load bearing (40kg) reverse jump, and used a 180 ° 5m turn back run as the direction indicator. The results showed that the peak explosive power and relative explosive power levels of the load bearing reverse jump were moderately correlated with the 5m turn back direction performance (r=-0.38-0.49). Peterson et al.(2010) pointed out that peak explosive power is highly correlated with directional ability (r=-0.73). The above studies indicate that peak explosive power is moderately to strongly correlated with changing direction ability.

However, Young et al. (2006) tested the performance of professional athlete groups in reverse jumping and three 90 ° directional changes, and found a weak correlation (r=-0.1) between reverse jumping and directional ability. Salaj and Markovic (2011) pointed out that there is a weak correlation (r=-0.15-0.24) between the reverse jump of male athletes and the sliding and figure 8 cuts, and that explosive power can have a weak impact on the ability to change direction. The reason for this may be due to different test contents of the ability to change direction. The score of the directional deficit test can be described as the difference between the 505 test time and the 10m sprint time. The content of the directional deficit test distinguishes the sprint part from the directional action, objectively discarding the limitations of traditional directional test indicators. Emmonds, et al. (2017) found a high correlation (r=-0.557) between the relative peak explosive power of the female athlete population and the directional deficit. Thomas (2015) pointed out that there is a weak to moderate correlation (r=-0.24-0.45) between reverse jumping and directional deficit in multiple athlete groups. In contrast, the relationship between reverse jumping and 505 test and 505 improved test results is moderate to high (r=-0.38--0.69). The selection of directional ability and explosive power indicators to some extent affects their correlation results.

In summary, there are numerous indicators for evaluating the changing direction ability, and factors such as entry angle, number of changes, and running distance to some extent affect the performance of direction change. This may lead to differences in the correlation between direction change ability and leg explosive power. Most research results indicate a moderate to high correlation between leg explosive power and direction change performance, and leg explosive power is an important factor affecting changing direction ability.

3.2.3 Leg reaction strength

Reactive strength refers to the ability of muscles to store elastic potential energy through centrifugal stretching during the stretching and contraction cycle (SSC), and rapidly contract and output force towards the center (Eamonn, P. Flanagan. 2008). Sheppard et al. (2006) found in their study on the leg muscle strength model that constitutes directional ability that reaction strength is an important muscle strength factor affecting directional ability. The reaction strength index can be used as a test indicator to evaluate reverse force, which can be measured through deep jumping movements. The reaction strength index can be described as the ratio of jumping depth height to landing time (Eamonn, P. Flanagan. 2008).

Young et al. (2002) pointed out that bilateral jump depth (30cm) performance is moderately to highly correlated with directional ability (r=-0.31-0.65), and unilateral (left, right) reaction strength index (15cm) is moderately to very correlated with directional ability (r=-0.43-0.71). The correlation coefficient between unilateral reaction strength and directional performance is slightly greater than that between bilateral reaction strength and directional performance. Castillo, Rodr í guez. et al. pointed out that the bilateral reactive power index of non athlete groups is moderately correlated with 90° and 180° directional performance (r=-0.34-0.54).

According to the coupling transition time from muscle centrifugation to centripetal rotation (0.25s), SSC can be divided into Fast and Slow SSC. Reverse jumping and deep jumping can respectively evaluate the slow and fast SSC abilities. There is a certain relationship between the support conversion time and the angle of entry during the directional change action. The angle of entry affects the contact time between the support foot and the ground during the conversion period. When making a<75 ° small angle entry, the support conversion time is usually less than 0.25 seconds. On the contrary, when making a>75 ° (Barnes, J. L. 2007) large angle entry, due to the large braking demand, the contact time is usually more than 0.25 seconds. Barnes et al. compared the relationship between two SSC movement modes and directional performance, and found that the correlation coefficient between the 30cm jump depth score and the smaller angle directional performance was greater than its coefficient with the larger angle directional performance. The impact of reaction force level on the smaller angle directional performance was greater than that on the larger angle directional performance.

Barnes, et al. (2007) pointed out that changing direction ability is highly correlated with reverse jumping (r=-0.58) and reaction force index (r=-0.55), and both Fast and Slow SSC can have a significant impact on the ability to change direction. Delaney et al. (2015) pointed out that there is a moderate correlation (r=-0.44-0.45) between the reaction strength index of a group of rugby players and their 505 test scores. The changing direction ability and sprint are relatively independent body movement abilities, and the changing direction ability deficit can effectively evaluate the deceleration, conversion, and re acceleration abilities during the process of changing direction movements. Emmonds, et al. (2017) tested the directional deficit and deep jump performance of female athletes and found that deep jump performance was highly correlated with directional deficit performance (r=-0.54), confirming that reaction strength is one of the important factors affecting directional performance.

In summary, there is a higher correlation between reaction force and small angle (<75 °) steering performance compared to large angle steering performance (>75 °); The correlation coefficient between unilateral reaction force and directional ability is usually greater than that between bilateral reaction force and directional ability, and the impact of unilateral reaction force on directional ability is greater than that of bilateral reaction force.

3.2.4 Lower limb asymmetry

The factors of lower limb asymmetry in sports include joint mobility, flexibility, lower limb length, strength, and other phenomena. In this study, lower limb asymmetry mainly refers to the asymmetry of lower limb muscle strength. The process of braking deceleration, support conversion, and re acceleration in directional changes mainly relies on a single leg to overcome its own weight and torque. Therefore, during the braking deceleration, support, and ground pushing process, it may be affected by the muscle strength of the dominant and non dominant sides of the lower limb. Young et al. (2015) pointed out that there is a high correlation between right side reaction strength and directional performance (r=-0.54-0.59), and a limb with a higher level of reaction strength helps to quickly complete one side of the entry movement. Asymmetric lower limb muscle strength may affect the directional performance of the dominant and non dominant sides.

Bailey et al. (2013) pointed out a significant correlation between lower limb asymmetry and jumping performance (r=-0.34-0.52, P<0.05), and lower limb asymmetry is an important factor affecting jumping performance. Hoffman et al. (1996) investigated the relationship between dominant and non dominant side muscle strength and dominant and non dominant side steering ability, and found that there was a significant difference in steering ability between the dominant and non dominant sides of the lower limbs (P<0.05). However, there was no significant correlation between muscle strength asymmetry and overall steering performance.

Meylan et al. (2009) included directional variables in their study on directional ability and pointed out that the horizontal jumping ability of the dominant and non dominant sides is highly correlated with directional ability (r=-0.47-0.59), indicating that the horizontal explosive force of the dominant and non dominant sides is an important factor affecting directional ability. Spiteri et al. (2013) compared the directional performance of groups with different strength levels and pointed out that compared to subjects with weaker muscle strength, the strong group showed a significant mechanical advantage in the directional process. Chiang, C. (2014) tested the mid thigh equal length pull and improved 505 test in a group of American college athletes and pointed out that high-level leg strength groups can complete the improved 505 test faster. Asymmetric muscle strength on the dominant and non dominant sides may lead to asymmetry in the direction of the dominant and non dominant sides, but asymmetry in the lower limbs does not affect overall directional performance, which is consistent with Hoffman et al

3.3 Training methods for changing direction ability

Keiner et al. (2014) recruited 112 male football players for strength training and specialized training, and conducted intervention training twice a week for 2 years. The strength training group significantly improved their directional ability (5% -10%), and their post test results were significantly better than those of the specialized training group ($P<0.05$). Nimphius et al. (2012) investigated the effect of 14 weeks of leg strength training on the group turning ability of female handball players, and pointed out that the relative strength of deep squats is moderately to highly correlated with the results of 505 dominant and non dominant sides (r=-0.51-0.7). Leg muscle strength is an important factor affecting turning ability, and enhancing leg strength helps to improve turning ability.

The process of changing direction mainly relies on a single leg to complete braking deceleration, support conversion, and re acceleration actions in the vertical and horizontal directions. McCormick et al. (2015) investigated the impact of ultra isometric training on turning ability across multiple anatomical planes. They divided 14 high school female basketball players into frontal and sagittal training groups, and found that both groups significantly improved turning and turning performance. It is worth noting that the frontal and sagittal groups had a significant interaction effect on left leg jumping performance and left leg turning performance (P<0.05 Keller (2018)) The youth athletes were divided into vertical training group, horizontal training group, resistance training group, and explosive strength group. After 4 weeks of training, the horizontal training group, strength training group, and explosive strength group significantly improved their T-test results, while the vertical training group did not significantly improve the T-test. Horizontal training, leg strength training, and explosive strength training all helped to improve directional performance. On the contrary, The vertical training content has a weaker effect on the transfer of directional ability. Ram, í rez. Campillo et al. (2015) pointed out that the vertical horizontal training group significantly improved directional ability ($P \leq 0.05$), and the post test comparison results between groups showed that the vertical horizontal training group (-5.1%) was more effective in improving directional performance than the vertical training group (-2.5%); Compared with the horizontal training group (-1.9%), the vertical horizontal training group is more effective in improving directional performance (-5.1%), and directional variables can cause differential adaptation effects in the neuromuscular system. Integrating training content from two planes may be better than practicing on a single plane; Compared in a single direction, horizontal training content is superior to vertical training content in improving directional ability. Gonzalo, Skok. et al. (2019) selected 13-14 year old adolescent basketball players as subjects and arranged a 6-week experimental intervention. The V-shaped entry and 7.5m turn back indicators were selected to evaluate the ability to change direction. Compared with the bilateral vertical direction super equal length training group, the unilateral horizontal direction super equal length training group significantly improved the V-shaped entry and 7.5m turn back direction, and compared with the bilateral vertical direction super equal length training content, Integrating one-sided ultra long exercises in the horizontal direction is more helpful in improving directional ability.

Tous, Fajardo. et al. (2016) randomly divided 24 football players into a centrifugal vibration training group and a conventional training group. They pointed out that the centrifugal vibration training group significantly improved V-shaped entry, enhanced centrifugal force, and proprioception, which helped to enhance the body's ability to withstand higher levels of ground impact and turn the body's center of gravity to the target direction, ensuring that athletes maintain a high approach speed before entering, Improving proprioceptive control ability helps maintain good posture during rapid entry and turning towards the target direction.

In summary, training methods such as resistance strength training, ultra long training, combination training, centrifugal strength training, and unilateral training can all have a positive impact on the ability to change direction of movement. Given the mechanical characteristics of the directional action process, directional variables and other factors can affect the intervention effect of directional ability. Compared to a single direction, horizontal training content is usually more helpful in improving directional ability than vertical training content; Integrating training content from two directions is more effective in improving directional ability than training content from a single direction; Unilateral training of the lower limbs is more helpful in improving directional ability than bilateral training; Centrifugal force is one of the key factors affecting directional ability, and enhancing centrifugal force and body posture control ability can help improve directional ability. However, the training methods and means selected in the above studies are relatively single, and experimental intervention content cannot be formulated based on the mechanical characteristics and muscle contraction forms in directional actions.

3.4 Research on changing direction ability of volleyball

The characteristic of volleyball is its speed and variability, which determines that the phosphate system is the main energy supply system. Mobile footwork is the most fundamental aspect of volleyball, and mastering excellent mobile footwork has a great impact on all aspects of volleyball skills. The volleyball movement footwork is mainly reflected in the defensive team's quick and accurate movement, the movement during blocking, and the movement during attacking. It can be seen that the mobility of athletes plays an important role throughout the entire volleyball competition, and is also a key factor in winning the game.

Baokui, Wang (2005) proposed that the movement ability of volleyball players is mainly reflected in two aspects: movement speed ability and reaction ability. In volleyball, the ball flies quickly and for a short period of time, requiring athletes to accurately determine the flight trajectory and landing point of the ball in advance, and use good mobility to hit the ball to prevent it from landing and causing points loss.

Jinfeng, Gao (2015) pointed out that if athletes can familiarize themselves with the mobility of volleyball, it can also help improve the mobility of other sports. Because volleyball requires athletes to have high mobility, they need to be prepared for quick movements at all times in order to adapt to the situation on the field at any time.

Jinfeng, Li (2011) believes in "The Importance of Foot Movement in Volleyball Training" that the most basic skill in volleyball is the ability to move feet. Whether it is the receiving of the ball by the back row defensive players or the defense of the front row blocking players, volleyball players need to have good movement ability to cooperate and complete the movements. He also believes that training the ability to move feet can help improve their technical level.

Feng, Zhang (2014) believes in "An Analysis of the Importance of Footstep Movement Technology in Volleyball Training" that the training of volleyball players' footstep movement ability requires a combination of strong consciousness and physical fitness training in order to reflect the training of movement technology in competitions. Gaoqiang,Li (2016) selected 18 students from the volleyball special class and divided them into an experimental group and a control group in a snake like manner. After 8 weeks of intervention, the research results showed that the core stability training of the experimental group subjects can better improve the rapid directional movement ability of volleyball athletes, and the two are positively correlated.

Ianchong, Xu. (2018) used experimental research methods and found that functional strength training can better improve core strength after 8 weeks of experimental intervention, and has a more significant effect on improving volleyball mobility.

In summary, the current selection of volleyball players is mainly based on high scores, and the pace on the volleyball field is very fast. The excellent and decisive predictive ability of athletes, as well as their good physical fitness, are key conditions for winning the competition. Therefore, improving the ability of volleyball players to change direction and move has become very important. For example, when athletes are preparing to spike in a game, the defensive side needs to predict in advance and quickly move into place to complete the blocking action. However, there is a lack of research on volleyball mobility in China, so this study will explore the relationship between training methods and directional mobility through experimental methods, providing reference for future research and enriching the theoretical system of volleyball training.

3.5 changing direction ability test indicators and methods

Wei, Yang. et al. (2021) used the "T" test and the 505 test in their research on the test methods, influencing factors, and training strategies for the changing direction ability of football players. Jinjin, Dai et al. (2022) used the 30-meter straight sprint, the 505 test, and the T-shaped run to test the changing direction ability in their study on the correlation between trunk strength and jumping, sprinting, and changing direction performance of excellent young beach volleyball players. Fang, Wu (2024) used test indicators such as the "T" test and the Pro test in the research on the influence of integrated neuromuscular training on the changing direction movement ability of college football players. In conclusion, combined with the expert questionnaire, this study finally determines the 505 change-of-direction deficit (180º Change of Direction Speed) as the measurement indicator for changing direction ability. The specific test methods are as follows:

1)180º change of direction speed test

The change of direction (COD) test requires athletes to start in a standing position, with their dominant foot forward and exactly 0.5 meters behind the first timing line. The COD test consists of a 10-meter run, specifically: a 5-meter straight sprint, followed by a 180-degree turn, and finally another 5-meter sprint to complete the test. Research shows that this test has good test-retest reliability (Castillo, Rodríguez. et al., 2012). In all COD tests, both legs are required to be used during the turn. All sprint tests are repeated twice, and the best result of each test is selected for statistical analysis. A one-minute recovery time is allowed between each test. During all tests, participants are given strong verbal encouragement to ensure they go all out. To calculate the change-of-direction speed loss, a 10-meter straight sprint test is also carried out. The calculation method is to subtract the 10-meter straight sprint time from the COD test time. Change-of-direction time=COD test time-10-meter sprint time. To detect the start and end of the test, the Smartspeed split-timing system (Smartspeed, Fusion Sport, Australia) is used to collect the results. The light-beam gates, which are 70cm high, are deployed at the starting point and the finish line respectively. As shown in Figure 4.

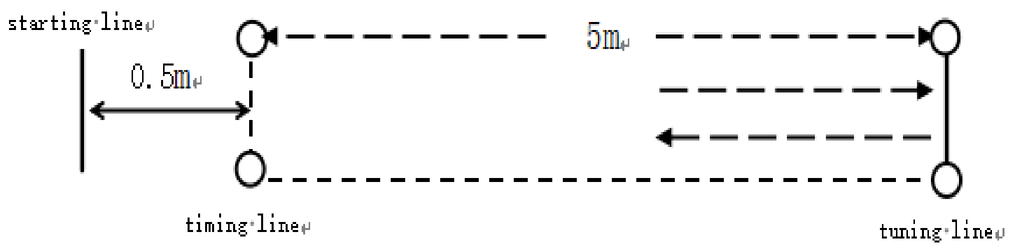

Figure 4 180° change of direction speed test

4. Research on complex training

4.1 Definition of complex training

More and more training methods are being developed and widely applied, such as resistance training to develop maximum muscle strength, enhanced and explosive training to improve movement speed, all aimed at scientifically and effectively simultaneously developing the strength and explosive power levels of athletes. This training method gradually developed to combine strength and explosive training in the same training class, which combines traditional resistance training with enhanced training (also known as ultra long training, rapid stretching complex training) or explosive training, known as complex training.(Ebben, W. P ; Watts, P. B.1998)

Tong,Zhou (2007) summarized and organized the relevant theories, concepts, methods, and loads of complex training in his research progress on complex training. It is believed that generalized complex training can arrange a series of training combinations based on the training purpose and changes in variables. However, currently, the term complex training specifically refers to the implementation of traditional resistance training and reinforcement training in the same training session, followed by reinforcement training that is similar to the biomechanical characteristics of resistance strength training.

In complex training, reinforcement training is an effective training method that can develop muscle explosive power levels. When training to develop explosive power levels, muscles undergo alternating training of centrifugation and centripetal contraction over a period of time, which is called enhanced training. Some scholars refer to reinforcement training as stretch complex training, but this definition is denied by others because equating reinforcement training with stretch complex training would appear too general, as stretch complex training includes two forms: "fast" and "slow". If fast stretch complex training is performed, it can be called reinforcement training.

4.2 Comparison between complex training and single form training

There are many empirical studies on complex training that compare its actual training effects with single resistance training or reinforcement training.

Adams et al. (1992) selected 48 subjects and divided them evenly into a control group and three experimental groups. The control group received traditional resistance strength training, with experiment I being the squat group, experiment II being the enhanced training group, and experiment III being the complex training group. The aim was to explore the effectiveness of the above training on improving the vertical jumping ability of athletes. Through short-term intervention training, the vertical jump height of the three experimental groups of subjects achieved significant improvement. Among them, the squat group athletes increased their vertical jump height by 3.3cm, the enhanced training group increased it by 3.81cm, and the complex training group showed a more significant improvement, reaching 10.67cm.

Zi, Wang; Tailin, Wang. (2018) used a complex training method to train the lower limb explosive power of college volleyball players in their "Practical Study on complex Training for Volleyball Athlete's Leg Pushing and Stretching Explosive Power" (Zi, Wang; Tailin, Wang.2018). The research results showed that compared with traditional resistance training, complex training showed varying degrees of improvement in the growth of lower limb explosive power of college male volleyball players. Complex training has a higher impact on the explosive power of volleyball players' lower limbs compared to traditional resistance training. Therefore, it is concluded that complex training is more conducive to improving the lower limb explosive power of college volleyball players.

In Ma Ce's "Research on the Influence of Complex Training on the Lower Limb Explosive Power of Young Male Basketball Players" (Ce, Ma. 2017), a complex training mode was adopted, which combines resistance training and reinforcement training, similar to the structure of basketball specific movements, and combines explosive training at the moment when the "post activation enhancement effect" of muscle strength training is positive. This training mode aims to improve explosive power, Gradually enhance muscle strength.

Previous studies on the practical utility of complex training have mostly focused on the vertical jumping ability of athletes as a detection indicator, because enhanced training is mostly based on jumping training methods. But some studies have also empirically studied the training effects of complex training using different evaluation criteria. Harriet (2016) selected seven military athletes for complex training and validated the short-term impact of complex training on speed quality using the 30m sprint index. The content is a complex training consisting of four sets of 60% 1RM and four 30m sprints, with an interval of 2 minutes. The results showed a significant improvement in the 30 meter sprint performance of the seven athletes. The research results indicate that complex training also has a good enhancing effect on whole-body, weightlifting, and throwing training (Lyttle, A. D, 1996; Matthews, M. J, 2010).

Many researchers believe that conducting strength training alone cannot meet the training needs, and that simultaneously conducting strength and speed training can better enhance the performance related to explosive power. For physical training, the key is for athletes to demonstrate better training effects during training. The introduction of complex training combines strength training with rapid stretching complex training, which not only enhances athlete's muscle strength but also improves movement speed.

4.3 Factors influencing complex training

The Intracomplex rest interval (ICRI) between resistance training and rapid stretching complex training in complex training is one of the key factors affecting training effectiveness. Long or short intervals can affect the effectiveness of an athlete's subsequent explosive power. The improvement in exercise performance after high-load resistance training is achieved through the increase in muscle strength obtained through PAP compared to exercise fatigue (Yinhui, Wang. 2020). The period during which exercise performance improves is called the "PAP window period" (Meifu, Liang. 2019). The PAP window period is divided into two stages. In the first stage, it exhibits a high level of explosive power; As the amount and intensity of exercise increase, fatigue dominates and exhibits poor exercise ability; After the completion of high-intensity training, as fatigue gradually subsides, PAP dominates and exhibits a high level of explosive power (Meifu, Liang. 2019). From Figure 4, it can be seen that the PAP in the second stage of the PAP window is more pronounced and lasts longer than in the first stage. The timing, duration, and size of PAP depend on the balance between enhancement and fatigue, which is influenced by multiple factors (Laurent,B. S 2016). Some researchers believe that the second phase of the

PAP window begins to appear 4 minutes after the end of the activation exercise, with the best enhancement effect occurring at 7-10 minutes and gradually disappearing from 12 minutes (Wilson, J.M. 2013). When the interval time is less than 4 minutes or more than 12 minutes, the effect of explosive power enhancement is not significant.

From numerous studies, it can be known that factors such as the load of resistance training, the strength and training level of athletes, and the selection of training movements can all have an impact on the production of PAP.

Research suggests that athletes with higher levels of strength produce greater PAP than athletes with weaker levels of strength (Laurent,-B.Seitz. 2014). Seitz et al. (2014) compared the differences in PAP among athletes with different strength levels. The results showed that athletes with higher strength levels exhibited higher levels of PAP compared to athletes with weaker strength levels, and PAP appeared earlier; Athletes with higher strength levels showed the greatest enhancement effect around 6 minutes after resistance training, while athletes with lower strength levels showed the greatest enhancement effect in the 9th minute. Seitz believes that the reasons for this are: 1) Athletes with higher strength levels may have a higher proportion of type II muscle fibers, leading to a higher degree of myosin phosphorylation; 2) Athletes with higher levels of strength may exhibit better fatigue resistance to larger loads after approaching maximum effort, which may quickly eliminate fatigue caused by resistance training. Another study by Seitz (Laurent, B.Seitz, 2016) reviewed numerous studies on complex training and explored the factors influencing PAP. The results showed that compared to resistance training with a load of 30% to 84% of 1RM, a load of 85% or higher at 1RM would produce a greater enhancement effect. This may be due to the increased recruitment of high threshold motor units caused by high load stimulation. However, Wilson et al. (Wilson, J.M; Duncan, N. M; Marin, P.J. 2013) suggest that a 60% to 84% 1RM intensity can mobilize higher-order motor units while reducing the risk of muscle damage caused by excessive intensity. Another study has found that under other unchanged conditions, different action amplitudes will lead to different enhancement effects. Esforms et al. (Joseph,I. Esforms. 2013) conducted a comparative study on 1/4 squat and half squat, and found that half squat can produce larger PAP compared to 1/4 squat. The interval time in complex training is a key influencing factor of training effectiveness. The interval time span involved in previous studies was large, ranging from 10 seconds (Randall, L. Jensen. 2003) to 24 minutes (Huw, R. Bevan. 2009). Seitz et al. (Laurent, B. Seitz. 2014) pointed out that compared to shorter intervals (30 seconds to 4 minutes), longer intervals (5-7 minutes or ≥ 8 minutes) can achieve greater PAP effects. This confirms the study by Wilson et al. (Wilson, J.M. 2013), which found that training with intervals of 3-7 minutes and 7-10 minutes resulted in better enhancement effects than training with intervals of 2 minutes. Bevan et al. (Bevan, Huw.R. 2009) suggest that an interval of 8-12 minutes may be the best choice for generating enhancement effects. As mentioned earlier, athletes with different levels of strength exhibit the greatest enhancement effect at different time points after conditioned activities, and the interval time between inducing the enhancement effect varies among different individuals. Batista et al. (Mauro, AB. Batista.2011) suggested identifying the optimal interval time for each athlete in scheduling complex training. However, in the actual training process, long intervals will lead to a significant waste of training class time. The National Physical Fitness Association of the United States recommends scheduling an interval of 2-5 minutes during complex training (Greg, Haff. 2016). Training volume and training intensity are two important aspects that affect the size of training load in a single training session or cycle. The combination of resistance training and rapid stretching complex training in the same training course should focus on training quality, maintaining high intensity and low load (Jeremy, Carter. 2014), to prevent an increased risk of injury. Each complex group in complex training should be arranged within the range of 2-5 groups. The number of repetitions of resistance training for each complex group is 1-5, and the number of repetitions of fast stretching complex training is controlled within 5-15; Alternatively, resistance training can use a load of 85% 1RM, while explosive training can use 75% of the maximum intensity (Tong, Zhou. 2017). However, this training arrangement method is not fixed and unchanging, and physical fitness coaches should arrange training days with different loads reasonably according to the cycle plan.

4.4 Research on complex training for volleyball players

Complex training, which adheres to the principle of "high intensity, few repetitions", is now widely used in the lower limb explosive training of male volleyball players. Due to the high efficiency of complex training in developing athlete strength and explosive power, it can effectively enhance the vertical jumping ability of male volleyball players. Therefore, in the current physical training of male volleyball players, complex training has become a favored training method by coaches. Complex training was first introduced to the training of high-level high jump and long jump athletes through a combination of strength and speed. Due to the similarity between sports, complex training methods have been widely applied to various sports dominated by fast strength, and volleyball is no exception. In the daily physical training of men's volleyball players, resistance training and jumping training for the upper and lower limbs are most widely used, but most coaches do not combine resistance training with reinforcement training in one training session to improve training efficiency. Therefore, the concept of "complex training" has filled this gap and enriched the means of daily physical training for male volleyball players.

5. Research on unilateral and bilateral strength training of the lower limbs

5.1 Research on unilateral strength training

In terms of lower limb strength training, Hao, Lu (2019) found that using the same weight-bearing squat training method, the exercise of non dominant legs can effectively improve the maximum strength, explosive power level, and jumping ability of both legs, which can improve the physical fitness and skill level of individual volleyball players, resulting in better sports results and performance. Xinghua, Huo (2014) stated in his study that the external oblique and internal oblique muscles of the quadriceps femoris, as well as the rectus femoris and the soleus muscle of the calf, are the main muscle tissues that provide strength for single leg vertical jumps. Peng, Zhang (2016) divided the experimental group into DS group (heavy squat group) and SS group (heavy single leg squat group) in single leg squat. After eight weeks of training, he analyzed the data indicators obtained before and after the experiment, and used deep squat for 1 rm, single leg squat for 1 rm, and standing triple jump. Tests were conducted on vertical jumps, single leg vertical jumps, and other events, and it was found that the increase in single leg weight squatting before and after the experiment was higher than that of double leg weight squatting. Hao, Lu (2019) compared and analyzed the data before and after the experiment using single leg push ups, barbell squats, and CMJ tests on both sides and legs. Based on the weight bearing squat exercises on both legs, it was found that independent resistance training was conducted on the inferior leg. The data results of non dominant leg, dominant leg, and both legs before and after training showed that the average score of single leg push ups, speed of leaving the take-off platform, and There is a significant difference between the vertical jump height and the average relative power. After analysis and comparison by previous scholars, the electromyographic information of the biceps femoris and rectus femoris of high-level female athletes in deep squats and Bulgarian single leg squats was analyzed and compared. Studies have shown that under the condition of Bulgarian single leg squats, the activation level of the biceps femoris and gluteus medius muscles is higher than that of deep squats. In addition, the knee joint eversion in a single leg squat with raised hind legs is more pronounced than in a deep squat, because the stability of the knee joint requires a higher degree of activation of the hamstring muscle during the stabilization process. Further analysis and research have not been conducted on other training actions.

In summary, after using heavy weight to increase single leg strength, the contribution in jumping speed and jumping height has significantly increased. There are very few opportunities for single leg takeoff in volleyball special takeoff movements. Generally, single leg takeoff is only used when organizing the secondary attack "backflight" fastball. However, this does not mean that it has no contribution to the jumping of volleyball players. Therefore, in this experiment, single leg strength training will choose single leg squat (Bulgarian single leg squat) as the strength training method for single leg.

5.2 Research on bilateral strength training

The effectiveness of leg squat exercises in improving maximum strength and explosive power has been proven, and squats are often used to train individuals for maximum strength or explosive power. Related studies have shown that eight weeks of deep squat practice can significantly improve the performance of young athletes in the 40 meter run, reverse jump height, and squat jump. Xinghua, Huo (2014) explained in his research that during the takeoff phase of a vertical jump, the excitability of muscles such as the soleus and gluteus maximus increases with load, while the excitability of the second and semitendinosus muscles first increases and then decreases. The medial and lateral muscles of the femur, rectus femoris, and gluteus maximus are the main muscles involved in the vertical jump process. Based on the basic techniques of dunking, firing, and blocking in volleyball, most of the take-off methods are leg jumps. Therefore, squatting is a relatively more suitable specialized strength training action. In this experiment, squatting was chosen as the training method for leg strength training.

5.3 Comparative study on unilateral and bilateral strength training

Young (2006) reported that bilateral vertical exercises (vertical jumps, squats, hard pulls, and Olympic weightlifting) have a weaker training effect on elite athletes. Although bilateral resistance training can effectively develop maximum strength, the transfer effect of sports performance caused by bilateral training is lower for elite athletes. Cronin et al. (Cronin, J; Ogden, T; Lawton, T. et al. 2007) pointed out that the maximum strength of back squats (23% -27%) has a lower transfer effect on the sprint ability of athletes in a group (2-3%). Comparing the intervention effects of different levels of athlete groups, amateur athlete groups usually show positive and significant intervention effects, while high-level athlete groups show lower intervention effects. Considering that high-level sports groups have years of training experience, in order to further improve their performance in specialized sports, training content should be developed based on factors such as the characteristics of specialized motor mechanics, energy supply system, and muscle contraction forms. Compared with bilateral training content, unilateral training is more in line with the principles of specialized training and can have a positive transfer effect on sports performance.

The concept of Bilateral Force Deficit was first proposed in 1961 (Henry, F. M. 1961). When two homologous limb muscles contract simultaneously, the maximum force produced by one limb will decrease, meaning that the force output from bilateral muscle contractions is lower than the sum of the forces produced by unilateral (left, right) muscle contractions (Bob, M. F.2006). Kuruganti et al. (Kuruganti, U; Philip, A; Parker, J; Rickards, M. et al. 2004) pointed out that six weeks of bilateral training can significantly reduce bilateral strength deficits in adolescent and middle-aged and elderly populations. Similarly, Taniguchi et al. (1997) compared the effects of six weeks of unilateral and bilateral training on bilateral strength deficits and pointed out that short-term unilateral training not only failed to reduce bilateral strength deficits, but also enhanced bilateral strength deficits, This is consistent with previous research perspectives. At present, the relationship between bilateral strength deficit and exercise performance and injury risk is still unclear. Therefore, coaches should not consider how unilateral and bilateral training affects bilateral strength deficit, but should focus on enhancing unilateral and bilateral muscle strength.

H ä kkinen. et al. (2010) pointed out that before and after bilateral strength training, the maximum strength of the bilateral group increased by 19%, and the left and right leg strength of the bilateral group increased by 11% and 10%, respectively; After unilateral strength training, the maximum strength of the unilateral group increased by 13%, while the left and right leg strength of the unilateral group increased by 14% and 17%, respectively. Single and bilateral training had a positive impact on single and bilateral strength, respectively. Makaruk et al. (2011) divided 49 female basketball players into a unilateral horizontal ultra long training group and a bilateral vertical ultra long training group. After 8 weeks of training, only the unilateral training group significantly improved peak explosive power. Short cycle (week) unilateral ultra long training was more effective than bilateral ultra long training in improving peak explosive power. After stopping training for 4 weeks, the bilateral group showed a significant increase in peak explosive power before and after 12 weeks of intervention ($P<0.05$) However, the peak explosive power of the unilateral group decreased significantly after 4 weeks of training cessation ($P<0.05$). Although unilateral training resulted in significant neuromuscular adaptation effects in a shorter period of time, the intervention effect lasted for a shorter period of time. Although bilateral training did not produce more positive neuromuscular adaptation in the short term, the intervention effect lasted longer.

Zhao, Sun (2017) conducted 8 weeks of single and bilateral strength training for female basketball players from U15 countries, and pointed out that the unilateral group significantly improved the performance of single leg vertical jump and approach double leg vertical jump ($P<0.05$), while the bilateral group only improved the performance of bilateral vertical jump ($P<0.05$). Unilateral resistance strength training had a positive impact on the explosive power of the lower limbs on both sides. Yilin, Que (2020) randomly divided 23 football players into a unilateral composite training group, a bilateral composite training group, and a specialized training group. After 6 weeks of intervention, the unilateral group significantly improved the T-test ($P<0.01$) and reverse jump ($P<0.05$). Compared with the bilateral group, the unilateral group significantly improved the T-test ($P<0.05$) and the total peak value of the left knee flexor extensor muscle at 180 degrees per second ($P<0.05$), Unilateral composite training has a better adaptive effect on neuromuscular function than bilateral composite training.

In summary, Unilateral complex training (lower limbs) refers to training in which the muscles of one leg contract and do work during training, such as lunge squats,single-leg jumps, etc.; Bilateral complex training (lower limbs) refers to training in which both legs contract and do work simultaneously, such as bilateral squats, frog jumps, etc.Unilateral training is a training method in which the unilateral limb is the main force-generating action mode. Its supporting theoretical system mainly comes from the cross-education effect and the bilateral force deficit effect.According to the Cross - education theory, after one limb is trained or practiced, the motor performance of the homologous limb on the other side will also improve. For example, when a player's right leg is injured and unable to perform strength training, through the strength training of the left leg, the strength level of the right leg can also be effectively improved. Manca et al. (2017) estimated through meta - analysis results that various forms of unilateral resistance training can induce an average strength gain of 11.9% in the untrained limb in the opposite direction, while the strength gains through isometric - dynamic training is 15.9%, and the gain using eccentric training can even reach 17.7%. In addition, according to the phenomenon of bilateral limb strength deficit, it has been found in training that using bilateral resistance exercises can cause bilateral strength deficiency. Specifically, when the forces generated by the muscle contractions of each limb are added together, it is often greater than the force generated by the simultaneous contractions of the muscles of both limbs. Belli et al. (2014) believe that the bilateral force deficit phenomenon exists because there are differences in the motor units recruited by unilateral and bilateral exercises. Secondly, the muscle coordination of the two modes of exercise is also different. During bilateral exercise, changes in the nervous system, especially the distraction of attention, will inhibit the activation degree of the nervous system. Using unilateral limb exercises in lower limb resistance training can complete a greater load than bilateral limb exercises and obviously can produce a greater stimulus to the target muscle groups. It can be seen that unilateral training can improve the training effect and training efficiency.

At present, there are more studies in China exploring the effects of single and bilateral compound training. Bilateral compound training is also widely used in ball games such as basketball, football, and badminton, but there is relatively little comparative research between single and bilateral compound training. I have summarized the theoretical and practical experience of previous scholars, combined with the characteristics of volleyball events, to explore the impact and differences of single and bilateral compound training on the maximum strength, explosive power, and directional ability of volleyball athletes in the lower limbs.

The summary: section mainly introduces the relevant research on maximum strength, explosive power, and changing direction ability of the lower limbs. The maximum strength and explosive power of the lower limbs are closely related to their changing direction ability. Explosive power is a key factor affecting athletes to complete high-intensity and explosive movements. Improving leg explosive power helps to enhance their changing direction ability. Previous studies have summarized the effects of various training methods on leg muscle strength and changing direction ability, but the most effective training method for developing changing direction ability cannot be determined (Falch, H.N. 2019). Complex training has a significant effect on improving the explosive power of athletes' lower limbs. After heavy resistance training, similar super isometric training is performed, and the enhanced effect of PAP is activated to improve the adaptability and explosive power level of athletes' nerves. Furthermore, through literature review, it can be seen that there is limited research on the effects of unilateral and bilateral complex training on the maximum strength, explosive power, and changing direction ability of volleyball players.

CHAPTER 3

RESEARCH METHODS

1. Research design

2. Research participant

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2.3 Sample selection criteria

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2.5 Sampling procedure

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4. Research methods and data collection

4.1 Research methods

4.2 Date collection process

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6. Data analysis

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1. Research design

This study was experimental research, aiming to compare the effects of unilateral and bilateral complex training of the lower limbs on developing the maximum strength, explosive power, and changing direction ability of volleyball players' lower limbs. During the experiment, two different training programs, namely unilateral complex training and bilateral complex training, were adopted. The training effects of the two training programs were measured by comparing the pre-test and post-test results of various indicators of the maximum strength, explosive power, and changing direction ability of the lower limbs. The research subjects of this study were ordinary college volleyball players and high-level college volleyball players. The specific research process was as follows: First, this study formulated the unilateral and bilateral complex training programs for the lower limbs of volleyball players through methods such as literature review, expert interviews, and questionnaire surveys, and determined the test indicators for the maximum strength, explosive power, and changing direction ability of the lower limbs of volleyball players. Then, through a formal experiment, it deeply compared the effects of unilateral and bilateral complex training in developing the maximum strength, explosive power, and changing direction ability of the lower limbs of volleyball players, so as to clarify the advantages of different training methods and provided scientific basis and practical guidance for the lower-limb strength training of volleyball players.

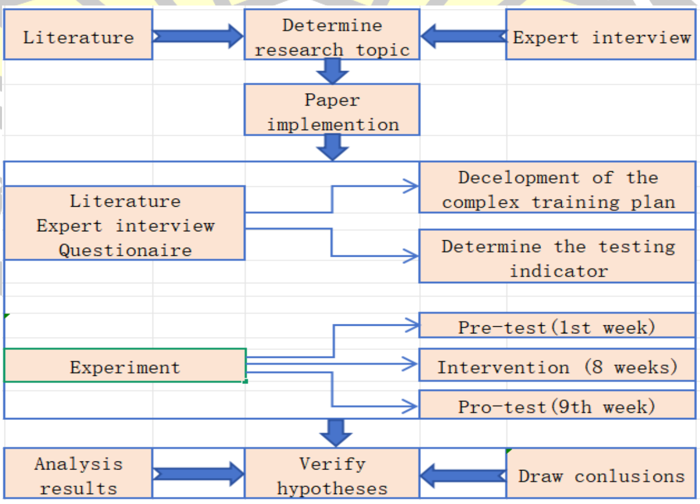

Figure 5 Research Framework

2. Research participant

2.1 Population

The research subjects of this study were male college volleyball players aged 18 to 24. The total number of male college volleyball players as research subjects consisted of 30 from Fudan University, 20 from Shanghai University of Finance and Economics, 46 from Shanghai University, and 48 from Shanghai University of Sport, totaling 144 people.

2.2 Composition of research subjects

In this study, for the pilot experiment with 30 participants: 15 people were selected from the 30 in Fudan University as the experimental group, and 15 people were selected from the 20 in Shanghai University of Finance and Economics as the control group. For the formal experiment with 68 participants: 34 people were selected from the 46 in Shanghai University as the experimental group, and 34 people were selected from the 48 in Shanghai University of Sport as the control group.

2.3 Sample selection criteria

2.3.1 Inclusion criteria

1) All volunteers agreed to participate in the study and fully understanded the purpose of the study and all testing procedures.

2) All 68 volunteers had participated in volleyball training for 2 years or more, aged 18-26 years, and had no obvious sports injury in the past 3 months.

3) All volunteers' training was scheduled during regular weekly training hours.

2.3.2Exclusion criteria

1)The athlete had not fully recovered from his injury in the last three months.

2) The athlete was taking medication for his illness.

3) Due to competition conflicts, the team members were unable to participate in all the normal training.

4) For other reasons, did not want to continue to participate in the experimental test.

2.4 Sampling size

In this study, the sample size was calculated using G - Power software (Version 3.1.9.7) (http://www.gpower.hhu.de/). According to Cohen (2013), both the ideal statistical power and effect size should be higher than 0.8. Based on this standard, the α error prob was set at 0.05, the research power was set at 0.8, and the effect size was set at 0.8. The calculated sample size for each group was 27 subjects. The specific calculation steps are as follows: Calculation formula: $n = \frac{(z_{1-\alpha/2}+z_{1-\beta})\times 2\times\sigma^2}{(\mu_1-\mu_2)}$.

Set α=0.05, $z_{1-\alpha 0.05/2}=z_{0.975}=1.96$. Statistical power 1- β=0.8, $z_{0.8}\approx 0.842$. The effect size d=0.8, The formula: $d = \frac{|\mu_1-\mu_2|}{\sigma}=0.8$. Substitute the above mentioned values into sample-size calculation formula:$n = \frac{(z_{1-\alpha/2}+z_{1-\beta})\times 2}{d^2} = 26.53 \approx 27$, sample size n=calculated subjects/(1-20%)=27÷0.8=33.75≈34.Thus, the calculated sample size for each group was 34 subjects. Therefore, the final sample size of this experiment was n = 34×2 = 68.A total of 94 volleyball players from Shanghai University and Shanghai University of Sport meet the requirements to participate in this experiment. It was planned to recruit 68 of them as experimental subjects and divided them into an experimental group and a control group, with 34 athletes in each group. For the convenience of centralized intervention training, the lottery method was adopted in this paper to conduct the grouping by school. 34 players from Shanghai University of Sport served as the experimental group and carried out unilateral complex training of the lower limbs. 34 players from Shanghai University served as the control group and carried out bilateral complex training of the lower limbs.

2.5 Sampling procedure

First, determine the experimental subject group according to the research purpose and questions. The research subject group of this study was college volleyball players. Second, through stratified sampling and purposive sampling, determine two levels of college high-level volleyball players and ordinary volleyball players as the research subjects. Third: Determine the sample size. Using G-Power software (http://www.gpower.hhu.de/) to calculate the sample size, and determined that the sample size was 68 people. Fourth: Screen and evaluate the experimental subjects. Further screen the selected experimental subjects to ensure that they meet the specific requirements of the research. For example, exclude individuals with certain diseases (injuries) or who did not meet specific conditions. Assess the willingness and feasibility of the experimental subjects to participate in the experiment by communicating face-to-face and issuing clarification documents to understand whether they were willing to participate in the experiment and whether they could complete various tasks during the experiment.

The composition, source and grouping of the final research subjects are shown in the figure below.

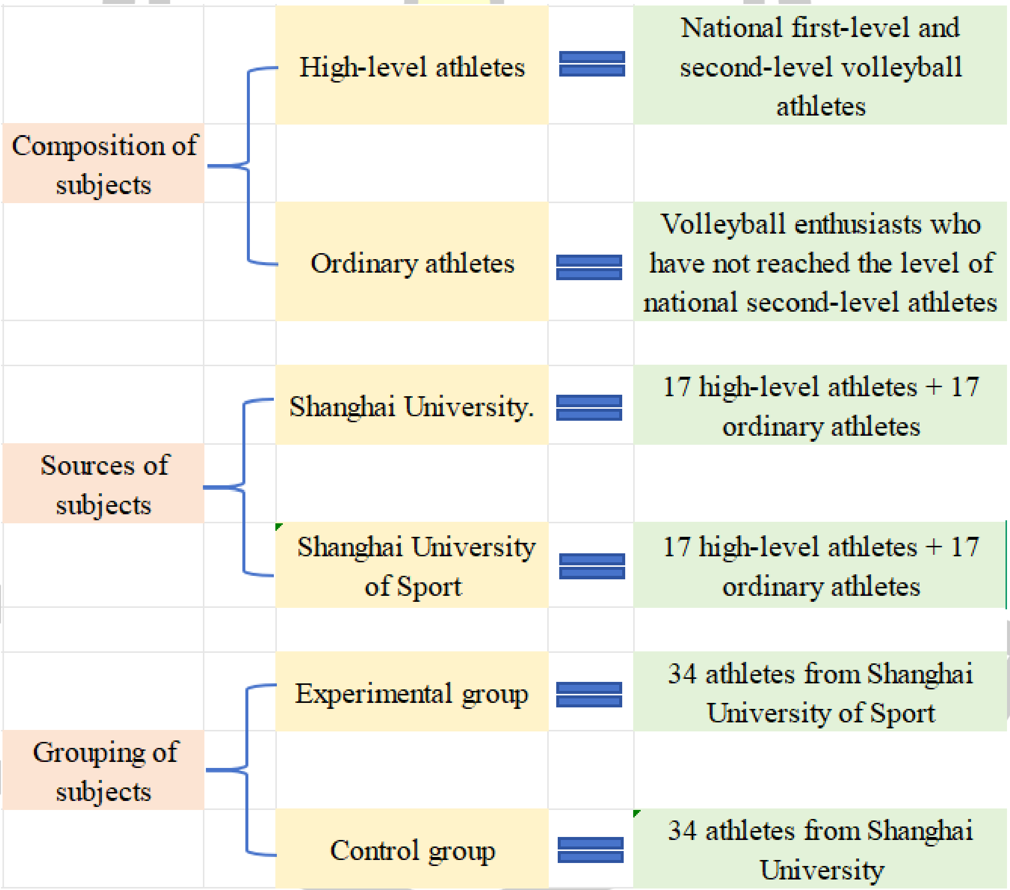

Figure 6 Composition and grouping of subjects

The information of the subjects is shown in Table 1 and Table 2.

Table 1 Basic situation of EG group volleyball players

Name	Age	Height(cm)	Weight(kg)	BFP(%)
CD	21	182	67.7	13.4
CKY	21	179	77.2	14.8
CYX	19	168	68	10.6
CHY	20	179	73.7	19.6
FYX	19	175	72.7	13.6
HJC	21	191	64.9	13.2
HJC	20	180	67.7	11.6
HRL	22	167	66	17.7
HYM	23	183	72	13.3
HZM	19	183	74.1	14.9
JW	20	181	72.20	16.20
LHY	20	170	65.60	10.30
LHY	19	187	88.60	12
LGZ	19	183	64.4	10.1
LP	19	183	82.1	20.2
WJ	23	185	77.3	13.8
JSJ	19	186	90.8	14
QRF	23	193	79.6	10.7
ZJT	21	193	93.1	18.6
THY	23	191	111.2	25.7
LBX	21	194	90.4	17.5
LX	22	190	79.5	15.3
XTC	21	197	100	19.8
CJL	22	192	110.1	20.1
ZN	22	188	85.3	17.6
TNH	21	195	90.6	17
LH	23	183	75.7	16.2
AMX	20	191	80.3	15
HYH	23	184	70.2	13.9
GZR	19	190	90.2	18.8
WZA	20	185	87	18.9
LYC	21	178	74.7	16.7
GJQ	22	190	89.6	18.9
JRJ	22	184	74.3	15.7

Table 2 Basic situation of CG group volleyball players

Name	Age	Height(cm)	Weight(kg)	BFP(%)
WXP	20	179	77.5	18.3
WZH	19	178	73.8	16.5
WZY	23	181	89.3	19.1
XRZ	20	194	75.1	10.6
YRAL	21	187	69.7	9.6
ZJY	22	183	73	10.2
ZYY	20	183	73	16.6
ZYZ	19	178	71.8	11.7
ZJM	20	183	78.1	13.3
ZCY	19	182	89	14.9
LQC	20	169	65.9	13.2
GSH	22	181	70.3	11.9
GYH	19	186	79.5	12
FJJ	20	170	60	10.1
LYL	19	175	62.3	10.2
YZZ	19	178	92.6	15.8
LFH	20	181	77.2	12.7
DL	22	190	75.2	13.9
DZF	21	190	76.7	14.1
TR	22	195	87.1	16.3
CDH	22	192	80.6	15.1
SYW	23	190	83.6	16.9
ZJW	21	195	93.2	18
ZTQ	22	193	89.7	17.8
WLZ	21	185	75.6	15.1
TZB	22	188	80.8	13.4
WYF	21	187	103.8	20.9
WYY	20	179	80.3	18.2
LYN	23	183	93.9	23.4
CSQ	19	195	87.5	10.2
FZY	20	206	87.9	15.7
SJX	21	191	91.2	16.3
ZBT	22	189	76.3	11.5
ZWF	22	192	110.1	27

3. Research tools and equipment

3.1 Experimental testing tools

1) Bounce force pad: (Smart-jump, Australia).

Smart-jump is a wireless and portable jump test pad that can be used for various forms of jump tests. This jumping test pad tests the jumping movement through pressure sensing, and can obtain data such as the athlete's touch time, hovering time, jumping height, reaction strength index, output peak power, relative power, leg stiffness, hovering time to touch time ratio, net centripetal impulse, etc.

2) Kistler force measuring platform (Kistler, Sweden)

The Kistler force measurement platform can measure data such as technical movements, gait, ground reaction forces in balance, torque, and pressure centers. Mainly applied to the evaluation of human movement, such as static balance, dynamic balance, movement and body direction change, rapid direction change movement, and strength and power testing.

3) Other: Smart speed split timing system (Fusion Sport, Australia), Velocity speed gun (Bushnell, USA), Body composition tester, etc.

3.2 Data collection tools

1) General Questionnaire

2) IOC Evaluation Form

3) Record sheet to record the test data before and after the experiment.

4. Research methods and data collection

4.1 Research methods

4.1.1 Literature data method

Through international academic journal databases such as the Shanghai University Library, Shanghai Sport University Library, China National Knowledge Infrastructure, Web of Science, SPORT Discous TM, Google Scholar, Science Direct, and Scopus, we conducted unilateral, bilateral, complex, resistance, strength, maximum strength, explosive power, changing direction ability, "Unilateral Training," "Bilateral Training," and "Complex Training." Search for relevant literature using keywords such as "Strength Training", "Explorative power", and "Changing direction ability". By organizing and refining domestic and foreign literature and books, sufficient theoretical basis and solid theoretical foundation were provided for the writing of this paper.

4.1.2 Ethical approval certificate number

1) Ethical Approval Certificate Number of Mahasarakham University:655-533/2024

2) Ethical Approval Certificate Number of Shanghai University:ECSHU 2024-076

4.1.3 Interviews

By reviewing relevant literature and books both domestically and internationally, and combining them with the theme of this paper, an interview outline was formulated. Semi structured interviews were conducted with experts and frontline coaches from Shanghai Sport University, Shanghai University School of Physical Education, Shanghai Men's Volleyball Team, and other units through visits, WeChat, Tencent meetings, and other forms. The author played a certain degree of control over the interview content.

The interview contented mainly focuses on two aspects. First, how to arrange volleyball players to conduct unilateral complex training for the lower limbs (used by the experimental group - the unilateral complex training group) and bilateral complex training (used by the control group-the bilateral complex training group) scientifically and reasonably. For example, how to determine the unilateral complex training program and bilateral complex training program, and what issues should be paid attention to during the training process. Second, it was about the determination of test indicators for the maximum strength, explosive power and directional change ability of the lower limbs of volleyball players (see Appendix B). Interviews with experts on the above issues. The interview information and data served as the content and supplement of the questionnaire survey. The focus of this study was to compare the improvement effects of unilateral complex training and bilateral complex training on developing the maximum strength, explosive power and changing direction ability of the lower limbs of volleyball players. Therefore, determining scientific and reasonable training programs and test indicators was crucial to this study.

Summary of the results of the expert interview:

(1) The training modes of the unilateral complex training group and the bilateral complex training group were the same. The difference lay in that the team members in the unilateral complex training group completed the movements with one-sided legs, while the team members in the bilateral complex training group completed the movements with both legs, so as to ensure that the content of the training intervention was as similar as possible.

(2) In the training, multiple types of movements should have been combined to avoid repeating a single movement, so as to improve the training effect. For example, resistance training could include squats (front and back squat), Romanian deadlifts, half squats (front and back squat), Bulgarian split squats, weighted side lunges, etc.; plyometric training could include vertical jumps, alternate jumps, depth jumps, hexagon jumps, hurdle jumps, continuous step jumps, lateral hurdle jumps, sprinting.

(3) Arrangement of training intensity and volume. Experts suggested that the training intensity: the intensity of unilateral training should have been slightly lower than that of bilateral training because unilateral training placed a greater load on the unilateral limb. It was recommended that the intensity of unilateral training be 70%-80% of the maximum strength, and that of bilateral training be 80%-90%. Training volume: the volume of unilateral training could have been appropriately increased because unilateral training had a smaller impact on overall fatigue. It was recommended that the number of repetitions for unilateral training be 8-12 times per set, and that for bilateral training be 6-10 times per set.

(4) Length of the training cycle. Experts suggested dividing the training cycle into a basic period (4-5 weeks) and an intensification period (4-5 weeks).

(5) Precautions during training. Experts suggested that: Standardization of movements: ensuring the standardization of each movement to avoid sports injuries

caused by non-standard movements. Core stability: strengthening the training of core muscle groups during training to improve the stability and control of movements. Individual differences: flexibly adjusting the training plan according to the age, training level and injury situation of athletes. Monitoring and feedback: regularly monitoring the training status of athletes, adjusting the training intensity and volume in a timely manner, and avoiding overtraining.

(6) Determination of test indicators. Experts suggested that: Maximum strength: adopting 1RM squat test, Relative peak strength of squat jumps, Mid-Pull Test, Isokinetic muscle strength test, etc.; Explosive power: adopting short-distance running, standing long jump, Vertical jump height in place, Approach Jump Height, Counter-Movement Jump, drop jump, Standing Triple Jump, etc.; Direction change ability: adopting T-test and 505 deficit turn test. Some test indicators combined with the specific events could also be arranged.

(7) Precautions for testing. Testing frequency: conducting tests once before training, in the middle of the training (after 5 weeks) and after training to monitor the training effect. Test standardization: ensuring the consistency of the test environment, equipment and process to improve the reliability of the test results.

4.1.4 Questionnaire survey method

4.1.4.1 Questionnaire design

In order to further determine the unilateral and bilateral complex training programs, as well as the testing indicators for maximum strength, explosive power, and changing direction ability, I consulted numerous relevant books and literature on volleyball physical fitness testing, sports measurement and evaluation, strength training, and complex training, and combined expert interview opinions to complete the questionnaire development of the "Questionnaire on Unilateral and Bilateral Complex Training Programs for Lower Limbs of Volleyball Athletes" (see Appendix B-Part 2) and the "Questionnaire on Testing Indicators for Maximum Strength, Explosive Power, and changing direction ability of Lower Limbs of Volleyball Athletes" (see Appendix B-Part 3).In the questionnaire, the indicators were rated on a scale of 1-5. Experts were invited to screen the indicators and provide suggestions to ensure the effectiveness and professionalism of the training plan.

4.1.4.2 Distribution and collection of questionnaires

Regarding the unilateral and bilateral complex training programs for volleyball players' lower limbs, as well as the test indicators such as maximum strength, explosive power, and changing direction ability, 12 sports research experts were invited for consultation. A total of 12 questionnaires were distributed, with a 100% recovery rate and all questionnaires being valid.

4.1.4.3 Item-Objective Congruence (IOC)

IOC is a method used to assess the alignment between test items and their intended measurement objectives. Introduced by Rovinelli and Hambleton in 1977, the IOC method ensures through quantitative analysis that each test item accurately measures the intended content, thus enhancing the test's content validity. The core principle of IOC involves expert evaluation to determine the degree of alignment between each test item and its intended objective. These experts are usually scholars or professionals with a deep understanding of the test content and objectives. The IOC method's key feature is its ability to transform subjective evaluations into quantitative indicators, facilitating the analysis and refinement of test items. Typically, 3 to 5 experts are invited to rate the relevance of each test item to its measurement objective on a scale from 0 to 1, where 0 indicates irrelevance and 1 indicates complete relevance. The IOC index for each item is then calculated based on these ratings. The specific calculation method is as follows:$IOC = \frac{\sum_{i=1}^{n} s_i}{n}$.

In this context, (Si) denotes the relevance score assigned by the (i) expert to a specific item, while (n) represents the total number of experts. The suitability of each item is assessed based on the IOC index value; generally, a higher IOC index indicates a stronger alignment between the item and its intended measurement objective.

The validity of the questionnaire was assessed using the Indexes of Item-Objective Congruence (IOC) by a five-member expert (the five experts were different from the twelve experts of the questionnaire) panel in this study. Five experts from different research fields evaluated the interview outline and made suggestions from different perspectives, Modifications were made based on expert opinions and a second round of IOC expert evaluation was conducted.The list of experts is as follows(Table 3).

Table 3 List of Evaluation Experts

Expert	Area	University	Title
LIu Bing	Sport Event; Sport Management	Shang Hai University	Professor
Shao Bin	Physical Education and Sports Training	Shanghai University of Sport	Professor
Lv Jidong	Physical Education and Sports Training	Shanghai University of Finance and Economics	Professor
Zeng Chaogong	Physical Education and Sports Training	Nanyang Normal University	Associate Professor
Guo Ping	Physical Education and Sports Training	Shang Hai University	High - level coach

The expert group assessed the consistency between the research purpose and the question designed at this stage. In the evaluation form, “-1” means the question was inconsistent with the purpose, “0” means uncertain, and the score “1” means the question design was consistent with the research purpose (see Appendix C). Scored by five experts, after calculation, when the value of IOC was greater than or equal to 0.5 (≥0.5), the project was valid (Turner; Carlson, 2003; Zubairi, Bt 2021).

In this study, five sports experts were invited to conduct an IOC evaluation of the "Questionnaire on Unilateral and Bilateral Complex Training Content for the Lower Limbs of Volleyball Players" and the "Questionnaire on Test Indicators for Maximum Strength, Explosive Power, and Changing Direction Ability of the Lower Limbs of Volleyball Players". The evaluation results are shown in Table 2 and Table 3.

In the evaluation of the training method questionnaire using the Index of Item-Objective Congruence (IOC), the IOC value of each item was greater than 0.5, indicating that the content validity of the items is reasonable.

In the IOC (Index of Item-Objective Congruence) evaluation of the questionnaire on test indicators for maximum strength, explosive power, and changing direction ability, the IOC value of each item is greater than 0.5. This indicates that the content validity of these items is reasonable.

Table 4 The IOC results of the questionnaire for training methods

Training methods		Results
Resistance training methods	Weighted Squat (Front Squat)	0.8
	Weighted Squat (Back Squat)	1
	Grip-style Squat	0.6
	Romanianl Deadlift	1
	Weighted Half - Squat (Front Squat)	0.8
	Weighted Half - Squat (Back Squat)	1
	Quarter Squat (Front Squat)	0.8
	Quarter Squat (Back Squat)	0.8
	Squat jump	1
	Weighted Sidestep	0.6
Plyometric training methods	Vertical jump	1
	Bounding jump	0.8
	Drop jump	1
	Hexagonal jump	0.8
	Continuous step - jumping	1
	Hurdle jump	1
	Side - hurdle jump	0.8
	stride jump	1
	straight - line sprint(15m)	1
	Vertical jump with knees hugged	0.6

Table 5 The IOC results of the questionnaire of test indicators

Test indicators		Results
Maximum strength	1RM squat	1
	Relative peak strength of squat jumps	0.8
	Isometric Mid-Thigh Pull	0.8
	Isokinetic muscle strength	1
Explosive power	Standing long jump	1
	Approach Jump Height	0.8
	Counter - Movement Jump (CMJ)	1
	Drop Jump (DJ)	0.8
	Squat Jump Takeoff Height	1

	5-meter sprint	1
	10-meter sprint	0.8
	Volleyball Special T-Test	1
	Jump-served ball speed	1
	Jump-spiked ball speed	0.6
Changing direction ability	180º Change of Direction Speed	1
	T-shaped running	1

4.1.4.4 Expert advice

1) Besides squats and Bulgarian split squats, it was recommended to add resistance training methods that conform to the specific movement patterns of volleyball to enhance the sport-specific relevance of the training.

2) According to the physical fitness development stages of athletes, precisely regulate the load intensity and avoid a one-size-fits-all approach to intensity setting.

3) Pay close attention to the athletes' conditions to ensure that the load volume could stimulate the body's adaptation without causing excessive fatigue and injuries. Ensure that athletes have a good basic physical fitness before undergoing intervention training.

4) It was suggested that in the initial stage of training, sufficient warm-up exercises and basic movement drills be carried out, and the training difficulty and intensity be gradually increased.

5) Special attention should be paid to the injury and illness conditions of athletes. Before the experiment, conduct a comprehensive injury and illness screening of athletes. It was not recommended that athletes who have had injuries or illnesses within the past three months participate in this intervention training.

6) Provide nutrition consultation and guidance to ensure that the athletes' nutritional intake during the experiment matches their training requirements.

4.1.5 Experimental method

4.1.5.1 Experiment time

Experimental period: November 2024-January 2025(see **Appendix D-table** 9)

4.1.5.2 Screening of training methods

In this study, the training methods were scientifically screened based on the weight values of the expert questionnaires. In the weight-calculation process, the Analytic Hierarchy Process (AHP) was adopted to calculate the weight values of each training method indicator. This method fully took into account the hierarchical relationships and mutual influences among different factors, making the weight-calculation results more logical and scientific. According to the calculated weight values, all the training method indicators were sorted in descending order. On this basis, the indicators with weight values ranking in the top 30% were selected as the preliminary screening results. Through the above-mentioned multi-dimensional comprehensive screening, the final training methods were determined. As shown in Table 4.

Table 6 Weight of training methods

Training methods		weight value (%)	rank
resistance training methods	Weighted Squat (Front Squat)	9.13	
	Weighted Squat (Back Squat)	12.39	2
	Grip-style Squat	7.39	
	Romanianl Deadlift	12.61	1
	Weighted Half-Squat (Front Squat)	12.17	
	Weighted Half-Squat (Back Squat)	12.39	2
	Quarter Squat (Front Squat)	9.13	
	Quarter Squat (Back Squat)	12.17	
	Squat jump	8.26	
	Weighted Sidestep	4.34	
plyometric training methods	Vertical jump	12.25	3
	Bounding jump	7.93	
	Drop jump	13.15	1
	Hexagonal jump	7.71	
	Continuous step - jumping	9.29	
	Hurdle jump	12.69	2
	Side-hurdle jump	11.11	
	stride jump	11.56	
	straight-line sprint(15m)	9.07	
	Vertical jump with knees hugged	5.21	

The results of the questionnaire survey show that among the resistance training methods, those with a weight proportion in the top 30% are Romanian Deadlift

(12.61%), Weighted Squat (Back Squat) (12.39%), Weighted Half-Squat (Back Squat) (12.39%). Among the plyometric training methods, those with a weight proportion in the top 30% are Drop jump (13.15%), Hurdle jump (12.69%), Vertical jump (12.25%).

Based on the above statistical results and combined with the concept of complex training, complex training (CT) combined traditional resistance training with plyometric exercises (plyometric training) (Blakeyl J B, 1987). In addition, according to the needs of unilateral and bilateral lower-limb training, the unilateral group will adopt there combined training methods: Bulgarian split squat with unilateral vertical jump, unilateral leg half-squat with unilateral leg drop jump, and unilateral leg deadlift with unilateral leg hurdle jump. The bilateral group will adopt there combined training methods: squat with bilateral leg vertical jump, half-squat with bilateral leg drop jump, and Romanian deadlift with bilateral leg hurdle jump. These training movements were based on the concept of complex training, that was, a plyometric exercise immediately follows a resistance training, following the principles and characteristics of complex training, and were in line with the core concept of complex training.

Summary: After screening and integrating the training approaches, the training programs for both the unilateral and bilateral groups had been determined. The details were summarized in Appendix D-table 10 and table 11 During the experiment, the training plans will be meticulously arranged to ensure that the training load and intensity were balanced between the two groups. The training movements adhered to the selected principles, providing clear training guidelines for both groups.

4.1.5.**3** Experimental process

This study used a comparative experiment method to Compare the effect of two different complex training methods on developing the maximum strength, explosive power and changing direction ability of the lower limbs of volleyball players. 68 volleyball players from Shanghai University and Shanghai University of Sport were selected as the experimental subjects. The subjects were divided into an experimental group and a control group, with 34 people in each group. The experimental group was the unilateral complex training group, and this group conducted unilateral complex training. The control group was the bilateral complex training group, and this group conducted bilateral complex training. After grouping, index test on body shape were conducted to check the differences between the two groups. Before and after the experiment, pre-tests and post-tests of the test indicators needed to be carried out, which should be completed within one week before the start and after the end of the experiment respectively. During the pre-test period, the maximum strength tests of squat, Bulgarian split squat, half-squat (both unilateral and bilateral legs), and deadlift (both unilateral and bilateral legs) were carried out on the subjects. The 1RM maximum strength data of the subjects' squat, Bulgarian split squat, half-squat (both unilateral and bilateral legs), and deadlift (both unilateral and bilateral legs) were collected to provide a basis for the control of the exercise load in the experimental intervention. After the training in the fourth week was completed and before the training in the fifth week, the 1RM maximum strength tests of the above items were conducted again to provide a basis for the control of the exercise load of the experimental intervention in the second stage (weeks 5-8). The experimental cycle was 10 weeks, with 1 week for the pre-test and post-test indicators respectively, and 8 weeks for the intervention training. The training was carried out twice a week, and each session lasts 90-100 minutes. The post-test of the experiment was conducted in the 10th week, and then the data were statistically analyzed and compared.

4.1.5.4 Experimental content arrangement

The subjects of the formal experiment were divided into two groups: the unilateral complex training group and the bilateral complex training group. The training contents of the two groups were different. Training content of the unilateral complex training group(as shown in Appendix D-table 10), including unilateral resistance training and unilateral plyometric training, etc. Training content of the bilateral complex training group(as shown in Appendix D-table 11), including bilateral resistance training and bilateral plyometric training, etc.

Note: The formal experimental intervention training period was 8 weeks, with training sessions held twice a week. The entire training cycle was divided into two stages. The first stage covered the first four weeks (1-4). During this stage, athletes in the same group had the same training content, training intensity, and training volume. The second stage was the subsequent four weeks (5-8), during which the training intensity and training volume would be adjusted. In the fourth week, a 1RM test would be conducted for athletes' squat, Bulgarian split squat, half-squat, and deadlift, and the 1RM values would be adjusted according to the measurement results.

Each training session consisted of three parts: warm-up exercise, intervention training, and cool-down exercise**.** The specific content was introduced as follows:

(1) Warm-up exercise: In this experiment, the warm-up exercise of the experimental group and the control group were the same. The warm-up activities were divided into two parts: jogging and dynamic stretching. The content of the first part was as follows: jog for 5 minutes. Through jogging, the body temperature and heart rate could gradually increase, and the viscosity of the muscles could be reduced, enabling the body to gradually enter the exercise state. The content of the second part of dynamic stretching includes: Hugging the knee and moving forward; Hugging the legs diagonally; Back cross lunge; Heel against the hip with the arm extended upwards; Lateral lunge movement; Balance stand; Backward lunge plus rotation; Sumo style squat; Crawling on all fours; The Greatest Stretching. Dynamic stretching was a kind of functional stretching. Through a series of dynamic and specialized stretching movements, the body can be further prepared for exercise, ensuring the effectiveness of the subsequent training and reducing the risk of injury.

Intervention training: For the training intervention part, the experimental group adopted the unilateral complex training method, while the control group adopted the bilateral complex training method. In this study, the unilateral group used three sets of training combinations: Bulgarian split squat with unilateral vertical jump, unilateral leg half-squat with unilateral leg drop jump, and unilateral leg deadlift with unilateral leg hurdle jump. The bilateral group used three sets of training combinations: squat with bilateral leg vertical jump, half-squat with bilateral leg drop jump, and Romanian deadlift with bilateral leg hurdle jump. The study pointed out that a training intensity of $\geq$ 80% of 1RM can lead to effective neuromuscular adaptation. To ensure the effectiveness of the intervention content, the training intensity in the resistance training of this study was set at 85%. The 1RM tests for squat, half-squat, and deadlift **were** conducted one week before the experiment and in the fourth week, and the load intensity was adjusted according to the actual situation.

In the unilateral group, from week 1 to week 4, the height of the drop jump box for the unilateral leg drop jump was 30 cm, and the height of the hurdle was 20 cm. In one set of exercises, the subjects first completed 4 repetitions of resistance training and then immediately carried out 7 repetitions of plyometric training with maximum effort, completing a total of 4 sets. From week 5 to week 8, the height of the drop jump box for the unilateral leg drop jump was 40 cm, and the height of the hurdle was 30 cm. In one set of exercises, the subjects first completed 5 repetitions of resistance training and then immediately carried out 10 repetitions of plyometric training with maximum effort, completing a total of 5 sets. The rest time within a set was 2 minutes, and the rest time between sets was 3 minutes. There **were** differences in the height of the drop jump box and the hurdle, as well as the number of training sets and repetitions between the first stage and the second stage.

In the bilateral group, from week 1 to week 4, the height of the drop jump box for the drop jump was 45 cm, and the height of the hurdle was 30 cm. In one set of exercises, the subjects first completed 4 repetitions of resistance training and then immediately carried out 7 repetitions of plyometric training with maximum effort, completing a total of 4 sets. From week 5 to week 8, the height of the drop jump box for the drop jump was 65 cm, and the height of the hurdle was 40 cm. In one set of exercises, the subjects first completed 5 repetitions of resistance training and then immediately carried out 10 repetitions of plyometric training with maximum effort, completing a total of 5 sets. The rest time within a set was 2 minutes, and the rest time between sets was 3 minutes. There **were** differences in the height of the drop jump box and the hurdle, as well as the number of training sets and repetitions between the first stage and the second stage.

(2) Cool-down exercise: Complex training had a relatively high impact intensity on the muscles, and a cool-down exercise was required after the training. Through the cool-down exercise, it could help the muscle tissue return to its initial length after exercise, significantly increase the oxygenation in the capillary area and the speed of red blood cells flowing to the muscles, which was conducive to the recovery of the muscles and alleviates the soreness caused after exercise. In this experiment, the content of the cool-down exercise for both the experimental group and the control group was the same, as follows: Stretching the hamstring muscles behind the thigh; Front thigh quadriceps stretch; Hip joint flexor muscle extension; Calf stretch; Gluteal muscle extension; Chest extension; Upper-Back Stretch; Shoulder extension.

4.1.5.5 Experimental condition control

(1) Throughout the entire experimental training process, all participants were required to wear sportswear and sports shoes.

(2) The training experiment was conducted twice a week, with a fixed schedule on Tuesday and Friday afternoons, to ensure muscle recovery and avoid the accumulation of fatigue affecting the training effect.

(3) Before the experiment, professional personnel with physical training qualifications provided technical action explanations and demonstrations, and supervision and guidance were provided during each experiment process.

(4) Before using relevant testing instruments and training equipment, they were checked and calibrated to ensure their reliability. All testing and training were monitored and guided by fixed personnel throughout the process, ensuring strict adherence to testing and training requirements.

4.1.5.6 Risk Assessment and Safety Measures

In this study, if volunteers follow the training requirements during training and fully perform warm-up and other preparations before training. the risk was relatively low, but there might be common exercise-related risks including muscle fatigue, minor muscle strain, or wrist sprain. Assess the potential risks in training and formulate corresponding preventive measures. Equip professional coaches and medical support during training to ensure the safety of subjects. The specific measures are as follows:

(1) On-site safety measures and first aid equipment

All trainings would be conducted in volleyball courts and physical fitness test venues that met safety standards, and there were no obstacles around the venues.

(2) Supervisors

Each training session would be supervised by at least one professional coach and two teaching assistant**s** to ensure training safety.

(3) Risk assessment

Subjects participating in this study were required to wear sportswear and sports shoes; arrange coaches to inspect the venue before training and eliminate potential dangers in time.

(4) First aid equipment

Each training venue was equipped with a first aid kit containing first aid supplies such as tourniquets, disinfectants, bandages, band-aids, and ice packs. Install an automated external defibrillator (AED) near the training venue.

(5) Professional medical situation

1)All coaches had received first aid training, including cardiopulmonary resuscitation (CPR) and the use of AED.

2) Ensure that the emergency response time did not exceed 5 minutes, and the ambulance from the nearby hospital could reach the training venue within 15 minutes.

(6) First aid steps

1) In case of minor injuries such as muscle strains or joint sprains, coaches and teaching assistants would use the first aid supplies on site for treatment in the first time, such as disinfection, bandaging, and icing;

2) In case of more serious injuries, such as heart problems, coaches and teaching assistants would perform cardiopulmonary resuscitation. At the same time, another teaching assistant would call the emergency number (the emergency number in China is 119), and the ambulance would arrive at the scene within 15 minutes.

(7) Persons in charge

1) On-site person in charge: During training or testing, the on-site person in charge was the sports team coach. In case of sports injuries or other issues, the coach would take immediate measures such as organizing first aid or calling the emergency number.

2) General person in charge: The researcher himself was the general person in charge of this experiment organization. During training and testing, the researcher was responsible for all problems that occur to athletes during training and testing. For example, all expenses related to sports injuries and other issues that occur to athletes during training were to be paid by the researcher.

4.1.6 Testing method

4.1.6.1 Testing time and location

Test time: The pre-test of the experiment would be completed in the middle of November 2024, and the post-test of the experiment would be completed at the end of January 2025.

Test location: Physical Training and Research Center

4.1.6.2 Screening of test indicators

In this study, the test indicators were scientifically selected based on the weight values from the expert questionnaires. During the weight-calculation process, the Analytic Hierarchy Process (AHP) was used to calculate the weight values of each test indicator. According to the calculated weight values, all test indicators were ranked in descending order. On this basis, the indicators with weight values ranking in the top 50% were selected as the preliminary screening results. Through the above-mentioned multi-dimensional comprehensive screening, the final test indicators were determined. As shown in Table 5.

The results of the questionnaire survey showed that among the maximum strength test indicators, those with a weight proportion in the top 50% are 1RM squat (32.07%) and Isometric Mid-Thigh Pull (30.44%); among the explosive power test indicators, those with a weight proportion in the top 50% are Counter-Movement

Jump (12.3%), Drop Jump (12.1%), 5-meter sprint (12.08%), 10-meter sprint (11.67%), Jump-served ball speed (11.25%), and Jump-spiked ball speed (11.25%); among the changing direction ability test indicators, the one with a weight proportion in the top 50% is 180º Change of Direction Speed (56.86%).

Table 7 Weight of Test Indicators

	training methods	weight value (%)	rank
Maximum strength	1RM squat	32.07	1
	Relative peak strength of squat jumps	15.21	
	Isometric Mid-Thigh Pull	30.44	2
	Isokinetic muscle strength	22.28	
Explosive power	Standing long jump	8.75	
	Approach Jump Height	6.67	
	Counter-Movement Jump (CMJ)	12.3	1
	Drop Jump (DJ)	12.1	2
	Squat Jump Takeoff Height	7.08	
	5-meter sprint	12.08	3
	10-meter sprint	11.67	4
	Volleyball Special T-Test	6.87	
	Jump-served ball speed	11.25	5
	Jump-spiked ball speed	11.25	5
Changing direction ability	180º Change of Direction Speed	56.86	1
	T-shaped running	41.14	

Based on the above statistical results, during the pre-test and post-test of the intervention training, the maximum strength test indicators were confirmed as 1RM squat and Isometric Mid-Thigh Pull; the explosive power test indicators are confirmed as Counter-Movement Jump, Drop Jump, 5-meter sprint, 10-meter sprint, Jump-served ball speed, and Jump-spiked ball speed; the changing direction ability test indicator was confirmed as 180º Change of Direction Speed.

4.1.6.3 Test procedures and content

4.1.6.3.1 Test Procedures

1. Pre-test preparation: (1) Explain the test purpose and procedures to athletes. (2) Conduct a 10–15-minute warm-up.

2. Test order: Maximum strength tests first, followed by explosive power tests, and finally changing direction ability tests; schedule 5-10 minutes of rest between each set of tests.

3. Post-test recording: Designate specific personnel to record each athlete’s test data to ensure accuracy.

4.1.6.3.2 Test content and methods

The purpose of this study was to compare the effects of unilateral and bilateral complex training on the maximum strength, explosive power, and changing direction ability of volleyball players. Therefore, the selected test indicators were relevant indicators that reflect the lower limb maximum strength, explosive power, and changing direction ability. In addition, the load intensity of the intervention training in this study required a reference basis. Thus, in the pre-test, the 1RM tests of half-squat and deadlift for the athletes in the bilateral group are added, and the 1RM tests of Bulgarian split squat, single-leg half-squat, and single-leg deadlift for the athletes in the unilateral group were also added.

(1) Maximum strength

1) 1RM test (Unit: kg)

The 1RM test includes squat, Bulgarian split squat, half-squat, and deadlift. Considering safety, the squat and half-squat were performed on a Smith machine with a fixed trajectory. Appropriate protection measures were also taken for the Bulgarian split squat and deadlift. The test standard followed the 1RM lower-limb test standard recommended by the NSCA (National Strength and Conditioning Association) of the United States. The method of increasing the weight during the test was adjusted according to the athletes' ability to increase the load incrementally.

Squat movement requirements: The subject stands with feet shoulder-width apart, slightly wider than the shoulders. Place the barbell behind the neck. Initiate the squat by flexing the hips, squat down until the thighs were parallel to the ground, and then fully extend the three joints of the lower limbs to an upright position.

Bulgarian split squat movement requirements: The subject's front and rear legs descend until the angle between the thigh and calf of both legs was 90 degrees, and the calf of the rear leg was parallel to the ground. The upper body leans slightly forward. The feet were shoulder - width apart, and the knees and toes werein the same direction.

Half-squat movement requirements: Stand with feet shoulder-width apart or slightly wider, and turn the toes slightly outward. Place the barbell on the trapezius muscle behind the neck, keep the back straight and the core engaged. Slowly squat down until the thighs were approximately at a 45-degree angle to the ground (half - squat position). Make sure the knees did not go beyond the toes, then use the strength of the legs and hips to push the body up and return to the starting position.

Deadlift movement requirements: Grasp the barbell with an overhand closed grip. Keep the barbell close to the shins. Push the feet against the ground, and simultaneously extend the hips and knees to lift the barbell. The barbell should rise along a vertical trajectory close to the body. Keep the torso completely upright, retract the scapulae, and fully extend the knees and hips.

2) Isometric Mid-Pull (Unilateral and Bilateral) (Unit: N)

The subject stands with feet shoulder-width apart. Place the barbell at the position of the second pull in the clean movement, with the middle part of the thighs closely against the crossbar. The subject wore weightlifting straps on both hands, which were fixed to the bar. The hip joint angle was 140-150° and the knee joint angle was 125-145°. For the unilateral isometric mid-thigh pull, the subject stands on one foot, with the non-supporting thigh parallel and close to the supporting side, and the knee joint flexed backward at 90°. Other test contents were the same as those of the bilateral test. After the start command was given, the subject exerts maximum forced continuously for 5 seconds, and the peak force was recorded. Data of the subject during this period was collected through a force plate (Winterthur, Swiss) and Mars software.

(2) Explosive power

1) Counter-Movement Jump(Unilateral and Bilateral) (Unit: cm)

The subject stands with feet shoulder-width apart and hands on the hips to avoid using arm swing for force. In the unilateral counter-movement jump test, the tester asks the subject to use one side as the supporting side in turn to complete the jump. The non-supporting thigh is parallel to the supporting side, with the knee joint flexed at 90 degrees. During the counter-movement jump test, the subject quickly flexes to lower the center of gravity. When the knees are bent about 90 degrees, the subject rapidly extends the three joints of the lower limbs to jump upward with force. The subject is required to complete the jump with maximum effort. The data of the subject's jump height during this period is collected using a three-dimensional force plate (Winterthur, Swiss) and Mars software.

2) Drop jump(unilateral and bilateral) (Unit: m/s)

The height of the unilateral drop jump is 15 cm, and the height of the bilateral drop jump is 30 cm. The subject stands on a 15-cm or 30-cm plyometric box, drops freely, lands on the force plate with one foot or both feet simultaneously, and then immediately jumps up with full force in the shortest possible time. A ground - contact time of ≤ 250 ms is regarded as a valid test. During the jump, the three joints of the lower limbs are fully extended in the air. Data of the subject during this period is collected through a force plate (Winterthur, Swiss) and Mars software.

3) Sprint (5m and 10m) (Unit: s)

The athletes start the sprint test in a standing position. Their designated front foot is placed behind the starting line, and then they accelerate forward with maximum effort until they pass through the last pair of photoelectric gates. The Smartspeed split - timing system (Smartspeed, Fusion Sport, Australia) is used to record the results at the 5-meter mark and the 10-meter finish line respectively.

4) Jump-served ball speed test (Unit: m/s)

Use a radar speed gun (Velocity speed gun, Bushnell, USA) to collect the data of serving speed. Subjects are required to complete the ball-speed test by performing an overhand jump - serve motion.

5) Jump-spiked ball speed test (Unit: m/s)

Use a radar speed gun (Velocity speed gun, Bushnell, USA) to collect the data of the of jump-spiked ball speed. Subjects are required to hit a standard volleyball with maximum force in a straight line towards the opposite court within the designated area.

(3) Changing direction ability

1) 180º change of direction speed test (Unit: s)

180 degree change of direction speed test requires the athlete to start in a standing position, with one foot exactly 0.5 meters behind the first timing gate. The COD test consists of a 10 - meter run. Specifically, the athlete sprints 5 meters in a straight line first, then turns 180 degrees, and finally sprints another 5 meters to complete the test. To calculate the change - of - direction speed loss, a 10 - meter straight - line sprint test is also conducted. The calculation method is to subtract the 10 - meter straight - line sprint time from the COD test time. Change - of - direction time = COD test time - 10 - meter sprint time. The Smartspeed split - timing system (Smartspeed, Fusion Sport, Australia) is used to collect the results. The photoelectric gates are respectively deployed at the starting point and the finish line, and the height of the photoelectric gates is 70 cm.

4.2 Date collection process

4.2.1 The interviews were conducted in the form of one-on-one personal interviews, small-scale meetings, or via telephone. The interview content and data were recorded.

4.2.2 The questionnaires for "training programs" and "test indicators" underwent IOC testing before distribution to ensure their validity and reliability. Based on the feedback from the respondents, it was necessary to adjust and improve some questions to make them clearer and more objective. The questionnaire survey was carried out through an offline method. Researchers need to manually collect and input the data according to the questionnaires filled out by the interviewees. During the statistics process, one volunteer was required to help with the review. Only after ensuring there were no errors can the data be input into the computer statistical table for statistical analysis.

4.2.3 Process of experimental data collection

1) After determining the experimental subjects, completed the data collection before the intervention experiment.

2) Established a record form to record the test data before and after the experiment.

3) Organized and carride out experimental interventions according to different training programs.

4) When the 8-week experiment ends, collected the test data after the intervention trial.

5. Experimental site

Test location: Shanghai Sport University Physical Training and Research Center and Indoor Strength Room

6. Data analysis

6.1 During the statistical stage of the questionnaire, the SPSS 26.0 software system was mainly used to conduct statistical analysis of the questionnaires. The median method and ranking method were adopted to statistically analyze the data information feedback from the experts.

6.2 During the statistical stage of the experimental data, the SPSS 26.0 statistical software was mainly used to conduct T - tests on the pre - test and post - test data of the experiment. When the sample size was greater than 30, according to the Central Limit Theorem, the sampling distribution of the sample mean will approach a normal distribution. For data that conform to a normal distribution, a t - test was carried out. An independent - samples t - test was conducted on the pre - test and post - test data between groups, and a paired - samples t - test was conducted on the pre - test and post - test data within groups. A P - value less than 0.05 indicates a significant difference, and a P - value less than 0.01 indicates a highly significant difference.

7. Research statistics

7.1 In this study, it was necessary to screen the training method indicators and measurement method indicators. During the weight - calculation process, the Analytic Hierarchy Process (AHP) was adopted to calculate the weight values . The weight values calculated by AHP could accurately reflect the contribution degree of each indicator to the overall research goal. Based on these weight values, all indicators could be scientifically ranked, and the indicators with higher weights could be selected as the final screening results.

7.2 In this study, it was necessary to compare the pre-test data between groups to ensure the comparability, that was, "homogeneity", of the data between the two groups. In addition, by comparing the difference values between the pre-test and post-test data, we determined the differences in the effects of the two training methods on improving the lower-limb strength of athletes. Therefore, in this paper, the independent-samples T-test was used to compare the pre-test data between groups as well as the difference data between the pre-test and post-test between groups.

7.3 In this study, it was necessary to understand the performance improvement of team members in the same group after the intervention training. The paired T-test could effectively control the interference of individual differences on the results and more accurately analyze whether a specific training method had a significant impact on the athletes in this group. Therefore, in this paper, the paired T-test was used to analyze the pre-test and post-test data within the group.

CHAPTER 4

RESEARCH RESULTS

In this chapter, according to the research objectives, SPSS 26 software was used to conduct T-tests on the pre-test and post-test data of the experiment. When the sample size is greater than 30, according to the Central Limit Theorem, the sampling distribution of the sample means will approach a normal distribution. For data that conform to a normal distribution, a t - test was carried out. An independent - samples t - test is conducted on the pre - test and post - test data between groups, and a paired - samples t - test was conducted on the pre - test and post - test data within groups. A P - value less than 0.05 indicates a significant difference, and a P - value less than 0.01 indicates a highly significant difference.

Research objectives:

1. To compare the effects of unilateral complex training and bilateral complex training on the maximum strength, explosive power, and changing direction ability of volleyball players.

2. To compare the effects of unilateral complex training and bilateral complex training on the maximum strength, explosive power, and changing direction ability of a group of volleyball players.

Symbols used to indicate the results of data analysis:

n: Representing sample size

$\bar{X}$: Representing the average value

SD: Representing standard deviation

P: Representative significance value

T: Represents the magnitude of the difference between two samples.

1. Comparison of the data before and after the experiment in the control group (CG)

Table 8 Comparison of the data before and after the experiment in CG (n=34)

Variable		Pre	Post	t	p
		X̄±SD	X̄±SD		
Maximum strength	1RM Squat	115.18±18.58	138.29±23.85	-5.211	0.000**
	Isometric Mid-Thigh Pull (Bilateral)	2235.84±328.93	2559.44±308.11	-4.844	0.000**
	Isometric Mid-Thigh Pull (Left side)	1977.80±285.94	2134.09±223.99	-3.405	0.002**
	Isometric Mid-Thigh Pull (Right-side)	1958.86±241.95	2124.65±170.66	-3.812	0.001**
Explosive power	CMJ (cm) (Left side)	20.70±4.25	21.92±3.87	-3.496	0.001**
	CMJ (cm) (Right-side)	20.20±3.94	21.28±3.41	-4.037	0.000**
	CMJ (cm) (Bilateral)	43.01±6.02	47.62±4.65	-6.241	0.000**
	DJ(m/s) (Left-side)	0.72±0.17	0.75±0.14	-2.245	0.032*
	DJ(m/s) (Right-side)	0.70±0.16	0.74±0.12	-2.460	0.019*
	DJ(m/s) (Bilateral)	1.72±0.27	1.82±0.35	-3.349	0.002**
	5-meter sprint(s)	1.02±0.06	0.99±0.08	3.238	0.003**
	10-meter sprint(s)	1.74±0.09	1.68±0.09	5.630	0.000**
	Jump-spiked ball speed(m/s)	18.55±3.35	20.60±3.00	-4.558	0.000**
	Jump-served ball speed(m/s)	19.68±3.34	21.42±2.59	-3.326	0.001**
Changing direction ability	180º Change of Direction Speed(s)	1.15±0.11	1.13±0.14	2.286	0.029*

* *p*<0.05 ** *p*<0.01

Note: CG: Control group (Bilateral Complex Training Group)

From Table 8, after the experiment, the P values of maximum strength (1RM Squat, Isometric Mid - Thigh Pull (Bilateral, Left and Right)), explosive power (CMJ(Left, Right and Bilateral), DJ(Left, Right and Bilateral), 5m sprint, 10m sprint, Jump - spiked ball speed, Jump - served ball speed) and changing direction ability (180° Change of Direction Speed) are all less than 0.05. All indicators of the control group had significantly improved before and after the experiment.

2. Comparison of the data before and after the experiment in the experimental group (EG)

Table 9 Comparison of the data before and after the experiment in EG (n=34)

Variable		Pre	Post	t	p
		X̄±SD	X̄±SD		
Maximum strength	1RM Squat	110.62±20.22	128.59±23.42	-4.185	0.000**
	Isometric Mid-Thigh Pull (Bilateral)	2144.11±295.76	2421.26±346.36	-3.899	0.000**
	Isometric Mid-Thigh Pull (Left - side)	1911.81±244.76	2178.79±221.77	-5.103	0.000**
	Isometric Mid-Thigh Pull (Right - side)	1893.08±232.25	2177.44±251.07	-6.657	0.000**
Explosive power	CMJ (cm) (Left - side)	20.71±4.45	23.43±4.93	-6.618	0.000**
	CMJ (cm) (Right - side)	20.04±3.83	23.05±3.49	-7.366	0.000**
	CMJ (cm)(Bilateral)	43.71±5.47	45.44±6.22	-3.366	0.002**
	DJ(m/s) (Left - side)	0.71±0.18	0.79±0.15	-5.473	0.000**
	DJ(m/s) (Right - side)	0.70±0.18	0.78±0.15	-4.929	0.000**
	DJ(m/s) (Bilateral)	1.69±0.37	1.75±0.36	-3.133	0.004**
	5-meter sprint(s)	0.99±0.06	0.95±0.09	3.625	0.001**
	10-meter sprint(s)	1.72±0.07	1.62±0.10	8.324	0.000**
	Jump-spiked ball speed(m/s)	18.20±2.54	18.76±2.57	-3.733	0.001**
	Jump-served ball speed(m/s)	18.76±2.93	19.34±2.79	-3.201	0.003**
Changing direction ability	180º Change of Direction Speed(s)	1.13±0.12	1.10±0.14	3.755	0.001**

* p<0.05 ** p<0.01

Note: EG: Experimental group (Unilateral Complex Training Group)

From Table 9, after the experiment, the P values of maximum strength (1RM Squat, Isometric Mid - Thigh Pull (Bilateral, Left and Right)), explosive power (CMJ(Left, Right and Bilateral), DJ(Left, Right and Bilateral), 5m sprint, 10m sprint, Jump - spiked ball speed, Jump - served ball speed) and changing direction ability (180° Change of Direction Speed) are all less than 0.01. All indicators of the experimental group had very significantly improved before and after the experiment.

3. Comparison of the differences in pre and post-test variable between unilateral and the bilateral group

Table 10 Comparison of the differences in pre and post-test Variable between groups (n=34)

Variable		EG	CG	t	p
		$\bar{X}$±SD	$\bar{X}$±SD		
Maximum strength	1RM Squat	17.97±25.04	23.12±25.87	-1.049	0.294
	Isometric Mid-Thigh Pull (Bilateral)	277.15±414.48	323.61±389.56	-1.595	0.111
	Isometric Mid-Thigh Pull (Left - side)	266.98±305.07	156.29±267.66	-2.245	0.025*
	Isometric Mid-Thigh Pull (Right - side)	284.37±249.07	165.78±253.58	-2.257	0.024*
Explosive power	CMJ (cm) (Left - side)	2.72±2.40	1.21±2.02	-2.097	0.036*
	CMJ (cm) (Right - side)	3.01±2.39	1.08±1.56	-4.232	0.000**
	CMJ (cm)(Bilateral)	1.73±3.00	4.62±4.31	-3.802	0.000**
	DJ(m/s) (Left - side)	0.08±0.08	0.03±0.08	-3.011	0.003**
	DJ(m/s) (Right - side)	0.07±0.07	0.04±0.08	-2.490	0.013*
	DJ(m/s) (Bilateral)	0.06±0.11	0.10±0.18	-0.613	0.540
	5-meter sprint(s)	0.04±0.07	0.02±0.04	-2.087	0.037*
	10-meter sprint(s)	0.09±0.10	0.05±0.06	-2.622	0.009**
	Jump-spiked ball speed(m/s)	0.56±0.87	0.86±1.05	-1.897	0.058
	Jump-served ball speed(m/s)	0.59±1.07	0.92±1.08	-1.050	0.294
Changing direction ability	180º Change of Direction Speed(s)	0.08±0.13	0.04±0.06	-0.908	0.364

* p<0.05 ** p<0.01

Note: CG: Control group (Bilateral Complex Training Group);EG: Experimental group (Unilateral Complex Training Group)

From Table 10, the results show that in terms of maximum strength, there are significant differences in Isometric Mid-Thigh Pull (Left) and Isometric Mid-Thigh Pull (Right) (P <0.05). In terms of explosive power, there are significant differences in the indicators CMJ (Left), CMJ (Right), CMJ (Bilateral), DJ (Left), DJ (Right), 5m sprint, and 10m sprint (P < 0.05). The P - values of other indicators are all greater than 0.05, indicating no significant differences.

CHAPER 5

CONCLUSIONS, DISCUSSIONS AND SUGGESTIONS

1. Conclusions

1.1 As can be seen from Tables 8 and 9, after 8 weeks of intervention training, for the control group, the P - values of DJ (m/s) (Left - side), DJ (m/s) (Right - side), and 180º Change of Direction Speed before and after the experiment are all less than 0.05, indicating significant improvement, and the P - values of other variables are all less than 0.01, indicating very significant improvement. For the experimental group, the P - values of all variables before and after the experiment are all less than 0.01, showing very significant improvement. This indicates that both unilateral complex training and bilateral complex training can effectively improve the maximum strength, explosive power, and changing direction ability of athletes after 8 weeks of intervention training.

1.2 As shown in Table 10, after 8 weeks of intervention training, there are significant differences ($P < 0.05$) between the control group and the experimental group in improving the performance of Isometric Mid - Thigh Pull (Left - side), Isometric Mid - Thigh Pull (Right - side), CMJ (cm) (Left - side), CMJ (cm) (Right - side), CMJ (cm) (Bilateral), DJ (m/s) (Left - side), DJ (m/s) (Right - side), 5 - meter sprint, and 10 - meter sprint. The control group outperforms the experimental group in improving the performance of CMJ (cm) (Bilateral) ($P < 0.05$). Additionally, the control group also slightly outperforms the experimental group in improving the performance of several variables, including Isometric Mid - Thigh Pull (Bilateral), DJ (m/s) (Bilateral), Jump - spiked ball speed, and Jump - served ball speed. The experimental group outperforms the control group in improving the performance of Isometric Mid - Thigh Pull (Left - side), Isometric Mid - Thigh Pull (Right - side), CMJ (cm) (Left - side), CMJ (cm) (Right - side), DJ (m/s) (Left - side), DJ (m/s) (Right - side), 5 - meter sprint, and 10 - meter sprint ($P < 0.05$). The experimental group shows significantly greater improvement in 8 indicators than the control group, while the control group shows greater improvement in 5 indicators, and only 1 indicator is significantly better than that of the experimental group. The experimental results indicate that unilateral complex training is more effective than bilateral complex training in improving the performance of single - leg test items, as well as 5 - meter sprint and 10 - meter sprint. Bilateral complex training has a greater improvement effect on double - leg test items than unilateral complex training. Overall, the effect of unilateral complex training is better than that of bilateral complex training.

2. Discussions

2.1 As can be seen from Tables 8 and 9, after 8 weeks of intervention training, in terms of maximum strength, the 1RM Squat in the unilateral group and the bilateral group increased by 20.03% and 22.20% respectively; Isometric Mid - Thigh Pull (Bilateral) in the unilateral group and the bilateral group increased by 15.5% and 16.2% respectively; Isometric Mid - Thigh Pull (Left - side) in the unilateral group and the bilateral group increased by 12.4% and 9.1% respectively; Isometric Mid - Thigh Pull (Right - side) in the unilateral group and the bilateral group increased by 12.84% and 9.63% respectively. The statistical results of the differences between the pre - test and post - test of the above - mentioned test indicators show that the P - values are all less than 0.01, indicating very significant improvement. That is, both unilateral and bilateral complex training can effectively improve maximum strength, and the improvement effect is remarkable. Similarly, Brendyn B Appleby et al. (2019) explored the effects of bilateral and unilateral resistance training on the lower - body strength of adolescent rugby players. In an 18-week training program, 33 athletes were divided into two training groups and a control group, and they carried out back-squats and unilateral exercises twice a week. The study found that both types of training could effectively improve lower - body strength.

In terms of explosive power, CMJ (cm) (Left - side) in the unilateral group and the bilateral group increased by 14.34% and 6.9% respectively; CMJ (cm) (Right - side) in the unilateral group and the bilateral group increased by 16.73% and 6.14% respectively; CMJ (cm) (Bilateral) in the unilateral group and the bilateral group increased by 4.05% and 11.73% respectively; DJ (m/s) (Left - side) in the unilateral group and the bilateral group increased by 13.65% and 6.2% respectively; DJ (m/s) (Right - side) in the unilateral group and the bilateral group increased by 11.55% and 7.82% respectively; DJ (m/s) (Bilateral) in the unilateral group and the bilateral group increased by 4.11% and 6.12% respectively; 5 - meter sprint in the unilateral group and the bilateral group increased by 0.04% and 0.01% respectively; 10 - meter sprint in the unilateral group and the bilateral group increased by 0.019% and 0.027% respectively; Jump - spiked ball speed in the unilateral group and the bilateral group increased by 3.21% and 5.8% respectively; Jump - served ball speed in the unilateral group and the bilateral group increased by 3.43% and 5.24% respectively. The statistical results of the differences between the pre - test and post - test of the above - mentioned test indicators show that the P - values are all less than 0.01, indicating very significant improvement. That is, both unilateral and bilateral complex training can effectively improve explosive power, and the improvement effect is remarkable. Häkkinen et al. (1985) compared the changes in the rate of force development (RFD) of the lower - limb muscle groups by conducting periodic squat and depth - jump exercises on the subjects. The results showed that depth - jump exercises could not only increase maximum strength but also improve the rate of force development, thus enhancing the ability of the lower - limb muscles to generate force rapidly. Patrick Cormier (2020) proposed in his research that compared with resistance training or plyometric training alone, complex training has been proven to be more effective in improving the lower - limb explosive power level. Stern et al. (2015) divided 23 elite young athletes into a unilateral and a bilateral training group and carried out a 6 - week training intervention twice a week. The results showed that both training methods improved the performance of the athletes in various tests.

In terms of changing direction ability, 180º Change of Direction Speed in the unilateral group and the bilateral group increased by 0.4% and 0.29% respectively. The statistical results of the differences between the pre - test and post - test of the above - mentioned test indicators show that the P - values are all less than 0.05, indicating significant improvement. That is, both unilateral and bilateral complex training can effectively improve the changing - direction ability, and the improvement effect is significant. Stern et al. (2019) compared the effects of unilateral and bilateral complex training on the change - of - direction speed of football players and found that both unilateral and bilateral complex training improved the change - of - direction speed to different extents, which is consistent with the conclusion of this study.

2.2 As can be seen from Table 10, a T-test was conducted on the results of the 8 - week experiment. In terms of maximum strength, there was no significant difference ($p > 0.05$) in the training effects of maximum strength between the unilateral and bilateral groups in 1RM Squat and Isometric Mid - Thigh Pull (Bilateral) after the intervention training, indicating that the two intervention programs had the same effect. Similarly, Yang Jiaqun (2016) found a similar phenomenon when exploring the effects of Bulgarian split squats and squat training on the athletic qualities of male college students. After an eight - week intervention, there was no significant difference in the improvement of relative 1RM in squats between the two intervention methods. A recent study by Appleby et al. (2019) also showed similar results. This study investigated the effects of eight-week unilateral and bilateral strength intervention training and a three - week maintenance phase on the 1RM of squats and rear - foot - elevated lungs of rugby players. The results showed that all intervention groups increased the 1RM of squats ($ES = 0.79 \pm 0.40$) and rear - foot - elevated lungs ($ES = 0.63 \pm 0.17$), but there was no difference between the groups. There was a significant difference ($p < 0.05$) in the training effects of maximum strength between the unilateral and bilateral groups in Isometric Mid - Thigh Pull (Left - side) and Isometric Mid - Thigh Pull (Right - side) after the intervention training, meaning that there was a significant difference in the effects of the two intervention programs. The improvement range of the unilateral group in Isometric Mid - Thigh Pull (unilateral) was higher than that of the bilateral group. Zhang Wenfeng et al. (2023) studied the effects of unilateral (UNI) and bilateral (BI) training on athletic performance, especially in terms of jumping, sprinting, maximum strength, change - of - direction, and balance abilities through systematic review and meta - analysis. The results showed that UNI training was suitable for enhancing unilateral strength, while BI training was better for improving bilateral strength. Behm et al. (2009) pointed out that unilateral strength training activates more trunk core muscles and other stabilizing muscles compared to bilateral strength training, and unilateral strength training is beneficial for people with insufficient strength training experience. The author believes that both unilateral and bilateral strength training can improve the unilateral and bilateral maximum strength levels of athletes' lower limbs, and each has its own advantages. Bilateral strength training can use a greater load, while unilateral strength training will increase the recruitment and co - contraction of relevant antagonist muscle groups.

In terms of explosive power. First, for power - based explosive strength, there were very significant differences ($p < 0.01$) in the training effects between the unilateral and bilateral groups in CMJ (Left - side), CMJ (Right - side), CMJ (Bilateral), DJ (Left - side), and DJ (Right - side) after the intervention training. That is, there were significant differences in the improvement of power - based explosive strength between the two intervention programs. The improvement range of the unilateral group in CMJ (unilateral) and DJ (unilateral) was significantly higher than that of the bilateral group, while the improvement range of the bilateral group in CMJ (Bilateral) was significantly higher than that of the unilateral group. Stern et al. (2015) divided 23 elite young athletes into a unilateral and a bilateral training group and carried out a 6 - week training intervention twice a week. The results showed that both training methods improved the performance of the athletes in various tests. The unilateral training group had a significant improvement in the unilateral lower - limb explosive power test, and the bilateral training group had a significant improvement in the bilateral lower - limb explosive power test. The author believes that unilateral strength training and explosive power training are more effectively translated into the performance of unilateral tests. Second, for speed - based explosive power, there was a significant difference ($P < 0.05$) in the training effects of the 5 - meter sprint between the unilateral and bilateral groups after the intervention training, and a very significant difference ($P < 0.01$) in the training effects of the 10 - meter sprint. That is, there were significant differences in the improvement of speed - based explosive power between the two intervention programs. The improvement range of the unilateral group in the 5 - meter sprint and 10 - meter sprint was higher than that of the bilateral group, which is similar to the conclusion of other studies (Vasileios Drouzas et al., 2020). This study evaluated the effects of unilateral and bilateral plyometric training on the strength and performance of pre - adolescent football players through a 10 - week experiment. The results showed that unilateral training was superior to bilateral training and the control group in improving hamstring strength, sprint speed, and single - long leg jump. Xu Xiong (2024) mentioned in his research that in the 10m sprint, the difference in experimental group A with unilateral complex training was - 0.08 seconds, with an improvement rate of 4.2%, and the difference in experimental group B with bilateral complex training was - 0.02 seconds, with an improvement rate of 1.1%. That is, unilateral complex training is more conducive to improving the 10m sprint ability of athletes than bilateral complex training. Third, for specialized explosive - power performance, there was no significant difference ($P > 0.05$) in the training effects between the unilateral and bilateral groups in Jump - spiked ball speed and Jump - served ball speed after the intervention training. That is, there was no significant difference in the improvement of Jump - spiked ball speed and Jump - served ball speed between the two intervention programs. However, from the statistical results, the training effect of the bilateral group was better than that of the unilateral group. In volleyball, both Jump - spiked ball speed and Jump - served ball speed use a two - foot approach jump. Therefore, the improvement of Jump - spiked ball speed and Jump - served ball speed can reflect the improvement of the two - foot approach jump ability to a certain extent. This is similar to the relevant research conclusion of Xu Xiong (2024). In his research, it was found that the difference before and after the experiment in the experimental group with unilateral complex training was 2.25cm, with an improvement rate of 0.7%; the difference before and after the experimental group with bilateral complex training was 5.13cm, with an improvement rate of 1.6%. The intervention method of bilateral complex training was more effective in improving the athletes' running two - foot take - off touch height and standing long jump. Of course, the improvement of Jump - spiked ball speed and Jump - served ball speed is affected not only by the strength of the lower limbs but also by other factors, such as the strength of the core muscle group and the strength of the upper - limb muscles.

In terms of changing direction ability, there was no very significant difference ($p > 0.05$) in the training effects of the 180º Change of Direction Speed between the unilateral and bilateral groups after the intervention training, meaning that there was no significant difference in the improvement of changing - direction ability between the two intervention programs. From the results, the improvement range of the unilateral group was better than that of the bilateral group, but not significantly. Thomas et al. (2018) investigated the relationship between various test indicators of the unilateral lower limb and change-of-direction speed. The author found a significant relationship between single-leg-hop and change-of-direction speed (CODS), and a significant relationship between single-leg countermovement jump and change-of-direction speed. The author believes that there is a correlation between unilateral lower-limb strength and change-of-direction speed and suggests developing unilateral lower-limb strength to improve change-of-direction speed. Stern et al. (2019) compared the effects of unilateral and bilateral complex training on the change-of-direction speed of football players and found that both unilateral and bilateral complex training improved the change-of-direction speed to different extents, with the unilateral group having a more obvious increase, which is basically consistent with the results of this intervention experiment.

3. Suggestions

3.1 Suggestions for applying research results

1). In terms of improving the maximum strength of the bilateral lower limbs (such as 1RM Squat, Isometric Mid - Thigh Pull (Bilateral)) , the research findings of this paper indicate that the effects of unilateral and bilateral complex training are basically the same. If the training focus is mainly on enhancing the maximum strength of the bilateral legs, coaches can make training arrangements based on other factors (such as training conditions, the training level of athletes, etc.) without considering which of the unilateral or bilateral lower - limb complex training is more effective.

2) Regarding the improvement of the maximum strength and explosive power of a single leg of volleyball players, the results of this paper show that unilateral complex training is more effective in enhancing the maximum strength and explosive power of a single leg than bilateral lower - limb complex training. Therefore, when considering the development of the single - leg lower - limb strength of volleyball players, coaches can consider including unilateral lower - limb complex training in the training plan.

3) In actual training, it is recommended not to abandon any training method, as each method has its own advantages and disadvantages. Coaches should rationally integrate and utilize both unilateral and bilateral complex training methods to help athletes achieve more comprehensive improvement.

4) In terms of enhancing the jump - related explosive power of volleyball players (such as the explosive power during spiking and serving), although the statistical results show that the bilateral training effect is slightly better in terms of Jump - spiked ball speed and Jump - served ball speed, the overall difference is not significant. This indicates that spiking and serving jumps are affected not only by lower - limb strength but also by core strength and upper - limb strength. Coaches are advised to combine the training of upper - and lower - limb strength and core strength in jump - serving and spiking training.

5) In the arrangement of the daily training cycle of volleyball players, the proportion of unilateral and bilateral lower - limb complex training should be flexibly adjusted according to the training goals of different stages. In the basic strength reserve stage, more emphasis can be placed on bilateral lower - limb complex training to improve the overall strength foundation. In the special - ability improvement stage, especially for technical movements that require single - leg explosive power and flexibility, the frequency and intensity of unilateral lower - limb complex training should be appropriately increased to closely integrate the training with the actual combat needs of volleyball.

3.2 Suggestions for future research

1) Given the unique characteristics of volleyball players at different levels, genders, and playing positions, it is necessary to refine aspects such as rest intervals and load intensity in future research. More precise intervention programs should be developed. For example, compared with novice players, elite players may be able to endure higher load intensities and shorter rest intervals. Players in different positions, such as setters, spikers, and blockers, may require specific training focuses.

2) It is recommended to extend the intervention duration in future research. By conducting interventions over a longer period, the improvement effects of various indicators can be further verified.

3) In future research, the comprehensive effects of different combinations of training methods can be explored. For instance, organically combining unilateral and bilateral compound training may potentially uncover training programs that maximize the development of volleyball players' lower - limb maximum strength, explosive power, and changing direction ability.

4) New technologies can be incorporated into future research. For example, the rational use of wearable devices for training monitoring can provide real - time data on athletes' movement patterns, muscle activation, and fatigue levels during training. By leveraging these technologies, researchers can gain a deeper understanding of the physiological and biomechanical responses to training, thus formulating more accurate and personalized training programs. Meanwhile, it is suggested to integrate neuroelectrophysiological techniques (such as surface electromyography and electroencephalography) to study the real-time interaction between muscles and the nervous system during training, providing a scientific basis for training optimization.

5) Future research can focus on the relationship between athletes' mental toughness and training effectiveness. Study the impact of different training methods on athletes' mental toughness, as well as how to enhance mental toughness through training, enabling athletes to better demonstrate their physical capabilities in high - intensity competitions.

6) Future research should further explore the correlation between changes in muscle strength and the nervous system, particularly in the application of complex training. For example, investigating the effects of unilateral and bilateral complex training on neuromuscular coordination, motor unit recruitment patterns, and central nervous system adaptability. By integrating multidisciplinary approaches such as physiology, biomechanics, and sports science, the potential mechanisms of training on the synergistic effect between muscles and the nervous system can be revealed, providing theoretical support for the development of more efficient training programs.

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ABBREVIATIONS

EG	Experimental group
CG	Control group
SSVL	Shanghai Campus volleyball league
BMI	Body Mass Index
1RM	One Repetition Maximum
CMJ	Counter - Movement Jump
DJ	Drop jump

APPENDIX

Appendix A

Ethic Certificate

MAHASARAKHAM UNIVERSITY ETHICS COMMITTEE FOR RESEARCH INVOLVING HUMAN SUBJECTS

Certificate of Approval

Approval number: 655-533/2024

Title : Effects of Unilateral versus Bilateral Complex Training on the Development of Strength, Explosive Power and changing direction ability of Volleyball Players.

Principal Investigator : Yan Sun
Responsible Department : Faculty of Education
Research site : Shanghai city, China

Review Method : Full Board Review

Date of Manufacture : 31 October 2024 **Expire : 30 October 2025**

This research application has been reviewed and approved by the Ethics Committee for Research Involving Human Subjects, Mahasarakham University, Thailand. Approval is dependent on local ethical approval having been received. Any subsequent changes to the consent form must be re-submitted to the Committee.

Ratree S.
....
(Assistant Professor Ratree Sawangjit)
Chairman

Approval is granted subject to the following conditions: (see back of this Certificate)

ECMSU01-06.03 English 2021

Informed consent form for research from volunteers
(For volunteers over 18 years old)

I (Mr.) ....Surname ....Age.............Year.
House number .... Village No. ....
Sub-district .... District .... province.......................

I have read the explanation / listen to the explanation from Mr. Yan Sun about volunteering in the research project on "Effects of Unilateral versus Bilateral Complex Training to the Development of Strength, Explosive Power and changing direction ability of Volleyball Players", the explanatory text consists of Full details about the origin and purpose of the research, details of the research. That I have to do and be treated, the benefits that I may gain from the research and the risks that may arise from participating in the study. Including guidelines for questions that may arise throughout. It has also received an explanation and an answer to any questions from the research project leader.

As well as the testimony from the researcher that will keep my information confidential. In addition, not anonymously or private information individually to the public. The results of the research will be presented in the form of an overview that is a summary of the research results for academic purposes only.

"In participating as a volunteer of this research project I join voluntarily." And I can withdraw from this study at any time. If I wish which will not have any effect and will not lose any rights in study or work that I will receive in the future.

I understand the contents of the volunteer statement. and this form of consent has been signed here.

sign................................ Volunteers
(.......................................)
Date..

sign................................ ...witness
(.......................................)
Date..

sign...................................researcher
(Mr. Yan Sun)
Date...

Chinese address:No. 99, Shangda Road, Shanghai, China . Chinese Phone:+8618116209612

ECMSU01-06.03 English 2021

Study informed consent from the volunteer head coach

I (Mr.) ....Surname .... Age............ Year.

House number ....Village No. ....

Sub-district ....District ....province..................

Convenient phone ....Email address ....

I read the explanation / listen to the explanation from Mr. Yan sun about volunteering in the research project on "Effects of Unilateral versus Bilateral Complex Training to the Development of Strength, Explosive Power and changing direction ability of Volleyball Players", the explanatory text consists of Full details about the purpose of the research, details of the research. I agree with the value of the study, I understand the benefits that my team members may gain from participating in this research and the possible risks, including the guidance on possible problems. Explanations and answers to any questions from the head of the research project were also received.

The researcher promised to keep confidential information from the members about my volleyball team. In addition, anonymous or private information may not be made available to the public alone. The findings will be presented in the form of an overview, which is a summary of the findings for academic purposes only.

"As the volunteer's coach, I gave them permission to participate in the study.". I agree that my recommended volunteers can withdraw from the study at any time. This will have no impact and will not result in the loss of any right to study or work in the future.

sign............................. Head coach

(........................)

Date..

sign.............................. researcher

(Mr. Yan Sun)

Date..

Chinese address: No. 99, Shangda Road, Shanghai, China . Chinese Phone:+8618116209612

Clarification documents for the volunteers who Experiment (answering questionnaires must over 18 years old)

Dear all Subject:

Because I (Yan Sun, PhD candidate, Health and Sport Science. Educational Faculty, Mahasarakham University) conducting research on "Effects of Unilateral versus Bilateral Complex Training to the Development of Strength, Explosive Power and changing direction ability of Volleyball Players". This study will help the coaching team Enrich strength training methods and means, make training more scientific and practical, improve and enhance athletes in strength training, improve their training level and effectiveness, and you may directly benefit from participating in this study.

After being interviewed by the researcher, you are eligible to be a volunteer for this study. If you decide to participate in this study, you will be asked to provide your basic personal information. If you feel uncomfortable with certain questions, you have the right not to answer them.

You and 67 other athletes will participate in an 8-week lower limb unilateral or bilateral complex training experiment. The indicators reflecting the maximum strength, explosive power and changing direction ability of the lower limbs will be tested one week before and one week after the experiment. The relevant explanations for testing and training are as follows: (1) The testing items include 1RM squat, unilateral and bilateral mid-thigh equal length pull, unilateral reverse jump and bilateral reverse jump, 15cm unilateral drop jump and 30cm drop jump, sprint 505 change of direction deficit, volleyball special T-test, Jump serve speed test, Spike speed test, etc. (2) During the 8-week experiment, it is necessary to strictly follow the coach's requirements, ensure sufficient sleep and a good diet, conscientiously complete training tasks, and not practice without permission. (3) The training during the experiment is similar to regular training, with different methods and requirements. The pre-experiment and post-experiment tests are also similar to regular tests. Please rest assured. (4) During the testing process, please follow the instructions of the on-site staff to complete the testing. (5) The risk of this study is relatively low, but there may be common exercise-related risks such as muscle fatigue, minor muscle strains, or wrist sprains.(6) I am the person in charge of the entire experiment. If you have any injuries or other problems during training or testing, I will be responsible for them, including the expenses involved in treating the injury and during the rehabilitation period.

You also have the right to withdraw from the program at any time without prior notice. And not participating in or withdrawing from the research project will not affect you in any way. Your Basic personal information will be retained and not disclosed to the public. Your Basic personal information will only be used for this study, and the relevant data will be destroyed after the study is completed. All participants' data will be encrypted and stored on the researcher's computer. Set the password for the folder where the data is saved and set the computer boot password. After the end of the experiment, all the experimental data on the experimental instrument will be deleted to ensure that the experimental data will not be leaked during the collection process. The analysis and digitization of the experimental data is carried out on the researchers' computers to ensure that there is no risk of data leakage. We will only use comprehensive information and data for reporting and will not disclose personal information of volunteers. You will not be paid or charged for the study.

If you have questions about the research, please feel free to contact me at (Yan Sun- Health and Sport Science. Educational Faculty, Mahasarakham University. Chinese address:No. 99, Shangda Road, Shanghai, China . Chinese Phone: +8618116209612).

If you were not treated as described or want to know your rights while participating in this study, you can contact at "Human Research Ethics Committee Mahasarakham University Division of Research and Academic Service Promotion Mahasarakham University "Tel. 043-754416 Internal number 1758

Sincerely

(Mr. Yan Sun)

Researcher

Appendix B

Expert Interview Outline Training Programs Test indexes and Questionnaire

Part I
Expert Interview Outline

1.Basic personal information of the interviewee

(1)Unit (Department):

(2) Cultural level: A.doctoral student B.graduate student C.undergraduate student

(3)Coach title: A. National level B. Senior level C .Intermediate level

(4)Teacher title: A .Professor B .Associate Professor C. Lecturer

2.Interview questions

(1)Do you think that complex training (i.e. strong resistance training+rapid stretching composite training) has a more prominent effect on developing lower limb explosive power in volleyball players compared to single resistance training and single rapid stretching load training?

(2)What are the commonly used methods for high-load resistance training of volleyball players (half squat and Bulgarian lunge squat)? What is the load intensity used (70% -100%)? How is the load capacity arranged (per group)?

(3) Can we use deep jump and long jump to develop the fast strength of volleyball athletes, and use the maximum distance of deep jump and long jump at the same jumping box height as the load intensity? In order to ensure that the load intensity of individual legs is the same, how is the load amount arranged?

(4) When conducting complex training for volleyball players, how to arrange the indirect time for resistance training and rapid stretching complex training? How to arrange the interval time between groups? Are there any intervals between the left and right legs during complex training? How to arrange it?

(5) What factors do you think should be excluded before the experiment that may interfere with the experiment?

Part II

《Survey questionnaire on complex training programs for volleyball players with unilateral and bilateral lower limbs》

Dear experts

I am a doctoral student majoring in Health and Sport Science. I am currently conducting my graduate thesis research entitled "Effects of Lower-Limb Unilateral Versus Bilateral Complex Training on the Development of Strength, Exploratory Power and Changing Direction ability of Volleyball Players". This study applies unilateral complex training to the lower limb strength and Changing Direction ability of volleyball players at Shanghai University, and uses experimental methods to demonstrate its effectiveness. To ensure the scientific, rational, and targeted design of the unilateral and bilateral complex training programs in this study, I kindly request that you can provide feedback on the initial selected complex training program in this article. Evaluation. Your personal information will be strictly confidential, and the information provided will only be used for research purposes in this article and will not be disclosed. Thank you for your help and support!

Please mark a √ on the question you have options for and fill it out truthfully.

1.Your unit name:_________________________.

2. Your position/title:______________________.

3. Your main research direction/field:_______________.

4. What is your understanding of unilateral strength training?

A. Very familiar B. Understood C. Relatively familiar D. Not very familiar E. Not familiar

5. What is your understanding of compound training?

A. Very familiar B. Understood C. Relatively familiar D. Not very familiar E. Not familiar

Instructions: The following table shows the resistance training and plyometric training methods for unilateral and bilateral complex training. There are 5 options, namely "5 Very important", "4 Important", "3 Moderately important", "2 Relatively unimportant", and "1 Unimportant". Please mark a "√" in front of the corresponding option when making your choice. In addition, if you have any other more reasonable suggestions, please fill them in the "______" space. Thank you very much.

Resistance training methods					
Movement name	5	4	3	2	1
Weighted Squat (Front Squat)					
Weighted Squat (Back Squat)					
Grip - style Squat					
Goblet Squat					
Weighted Half - Squat (Front Squat)					
Weighted Half - Squat (Back Squat)					
Quarter Squat (Front Squat)					
Quarter Squat (Back Squat)					
Squat jump					
Weighted Side Step					

Plyometric training					
Movement name	5	4	3	2	1
Vertical jump					
Bounding jump					
Drop jump					
Hexagonal jump					
Continuous step - jumping					
Hurdle jump					
Side - hurdle jump					
stride jump					
straight - line sprint(15m)					
Vertical jump with knees hugged					

Besides, what other single - leg and double - leg compound training methods do you think have an impact on lower - limb maximum strength, explosive power, and changing direction ability? Please fill in the blanks below. The suggestions you need to supplement:

Part III

《Survey questionnaire on testing indicators for maximum strength, explosive power, and changing direction ability of volleyball players》

Dear experts:

I am a doctoral student majoring in Sports and Sports Health. I am currently conducting my graduate thesis research on "Effects of Lower Limb Unilateral Versus Bilateral Complex Training on the Development of Strength, Exploratory Power and changing direction ability of Volleyball Players". This study applies unilateral complex training to the lower limb strength and changing direction ability of volleyball players at Shanghai University, and uses experimental methods to demonstrate its effectiveness. To ensure the representativeness of the selected test indicators in this study, I kindly request that you evaluate the initial test indicators in this article. Your personal information will be strictly confidential, and the information provided will only be used for research purposes in this article and will not be disclosed. Thank you for your help and support!

Instructions: The following table shows the test indicators for lower limb maximum strength, explosive power, and direction - changing ability.. There are 5 options, namely "5 Very important", "4 Important", "3 Moderately important", "2 Relatively unimportant", and "1 Unimportant". Please mark a "√" in front of the corresponding option when making your choice. In addition, if you have any other more reasonable suggestions, please fill them in the "______" space. Thank you very much.

Maximum strength indicators	5	4	3	2	1
1RM squat					
Relative peak strength of squat jumps					
Isometric Mid-Thigh Pull					
Isokinetic muscle strength					

Explosive power indicators	5	4	3	2	1
Standing long jump					
Approach Jump Height					
Counter - Movement Jump(CMJ)					
Drop jump(DJ)					
Squat Jump Takeoff Height					
5 meter sprint					
10 meter sprint					
Volleyball Special T-Test					
Jump - served ball speed					
Jump - spiked ball speed					

Changing direction ability indicators	5	4	3	2	1
180º Change of Direction Speed(s)					
T-shaped running					

Besides, what other test indicators do you think can reflect the lower limb maximum strength, explosive power, and change - of - direction ability? Please fill in the blanks below. The suggestions you need to provide:

Appendix C

IOC in Training programs Test indexes and Questionnaire

Dear experts:

Hello!

I am (Mr.Yan Sun, PhD Student Health and Sport Science. Faculty of Education, Mahasarakham University) under the advisor of Napatsawan Thanaphonganan,Ph.D, now doing on research name"Effects of Unilateral versus Bilateral Complex Training to the Development of Strength, Explosive Power and changing direction ability of Volleyball Players." With the objective (specify) :

1. To compare the effects of unilateral complex training and bilateral complex training on the maximum strength, explosive power, and changing direction ability of volleyball players.

2. To compare the effects of unilateral complex training and bilateral complex training on the maximum strength, explosive power, and changing direction ability of a group of volleyball players.

You are a senior expert with rich knowledge and experience. I sincerely ask for your guidance and help. I hope you can give me guidance and evaluation in your busy schedule and put forward your valuable opinions and suggestions.

Thank you very much for your support and help.

Student name: Yan Sun

Advisor: Dr. Napatsawan Thanaphonganan

Email: 53557282@qq.com

Mahasarakham University, Thailand

Please fill in the following personal information:
Expert's name:
Professional title:
Work unit:

Dear experts, the following is the Survey questionnaire on complex training programs for volleyball players with unilateral and bilateral lower limbs in this study. Please rate in the score column (-1 is not suitable, 0 is general, 1 is suitable between "√"), and give relevant modification suggestions in the topics that need to be modified. Thank you for your guidance and evaluation in the help.

Item	**IOC score for the expert**			**Suggestion**
	-1	**0**	**1**	
Part 1 : Resistance training methods				
1. Weighted Squat (Front Squat)				
2.Weighted Squat (Back Squat)				
3.Grip - style Squat				
4.Barbell load arrow squat				
5.Weighted Half - Squat (Front Squat)				
6.Weighted Half - Squat (Back Squat)				
7.Quarter Squat (Front Squat)				
8.Quarter Squat (Back Squat)				
9.Squat jump				
10.Weighted Side Step				
Part 2 : Plyometric training				
11.Vertical jump				
12.Bounding jump				
13.Drop jump				
14.Hexagonal jump				
15 Continuous step - jumping				
16.Hurdle jump				
17.Side - hurdle jump				
18.Straight - line sprint(15m)				
19.Vertical jump with knees hugged				

Please fill in the following personal information:
Expert's name:
Professional title:
Work unit:

Dear experts, the following is the **Survey questionnaire on testing indicators for maximum strength, explosive power, and** changing **direction ability of volleyball players** in this study. Please rate in the score column (-1 is not suitable, 0 is general, 1 is suitable between "√"), and give relevant modification suggestions in the topics that need to be modified. Thank you for your guidance and evaluation in the help.

Item	**IOC score for the expert**			**Suggestion**
	-1	**0**	**1**	
Part 1 : Maximum strength indicators				
1.1RM squat test				
2.Relative peak strength of squat jumps				
3.Mid - Pull Test				
4.Isokinetic muscle strength test				
Part 2 : **Explosive power indicators**				
5. Standing long jump				
6. Approach Jump Height				
7.Counter - Movement Jump(CMJ)				
8.Drop jump(DJ)				
9.Squat Jump Takeoff Height				
10.5 meter sprint				
11.10 meter sprint				
12.Volleyball Special T-Test				
13.Standing serve speed test				
14.Spike speed test				
Part 3 : **Direction - changing ability indicators**				
15.180º Change of Direction Speed(s)				
16.T-shaped running				

IOC results of Survey questionnaire on complex training programs for volleyball players with unilateral and bilateral lower limbs

Item	Exp1	Exp2	Exp3	Exp4	Exp5	Total	IOC value	Results
Part 1:Resistance training methods								
1. Weighted Squat (Front Squat)	1	1	0	1	1	4	0.8	Pass
2. Weighted Squat (Back Squat)	1	1	1	1	1	5	1	Pass
3. Grip - style Squat	1	1	0	1	0	3	0.6	Pass
4. Romanianl Deadlift	1	1	1	1	1	4	0.8	Pass
5. Weighted Half - Squat (Front Squat)	1	1	0	1	1	4	0.8	pass
6. Weighted Half - Squat (Back Squat)	1	1	1	1	1	5	1	pass
7. Quarter Squat (Front Squat)	1	1	0	1	1	4	0.8	pass
8. Quarter Squat (Back Squat)	1	1	1	1	1	5	1	pass
9. Squat jump	1	1	1	1	1	1	1	pass
10. Weighted Side Step	1	0	1	0	1	3	0.6	pass
Part 2:Plyometric training								
11. Vertical jump	1	1	1	1	1	1	1	pass
12. Bounding jump	1	1	1	0	1	1	0.8	pass
13. Drop jump	1	1	1	1	1	1	1	pass

14. Hexagonal jump	1	0	1	1	1	1	0.8	pass
15. Continuous step-jumping	1	1	1	1	1	1	1	pass
16. Hurdle jump	1	1	1	1	1	1	1	pass
17. Side-hurdle jump	1	0	1	1	1	1	0.8	pass
18. Straight - line sprint(15m)	1	1	1	1	1	1	1	pass
19. Vertical jump with knees hugged	1	1	0	1	0	3	0.6	pass

IOC results of Survey questionnaire on testing indicators for maximum strength, explosive power, and changing direction ability of volleyball players

Item	**Exp1**	**Exp2**	**Exp3**	**Exp4**	**Exp5**	**Total**	**IOC value**	**Results**
Part 1:Maximum strength indicators								
1. 1RM squat test	1	1	1	1	1	5	1	Pass
2. Relative peak strength of squat jumps	1	1	0	1	1	4	0.8	Pass
3. Mid-Pull Test	1	1	1	1	0	4	0.8	Pass
4. Isokinetic muscle strength test	1	1	1	1	1	5	01	Pass
Part 2:Explosive power indicators								
5. Standing long jump	1	1	1	1	1	5	1	Pass
6. Approach Jump Height	1	1	1	1	0	4	0.8	Pass
7. Counter-Movement Jump(CMJ)	1	1	1	1	1	5	1	Pass
8. Drop jump(DJ)	1	1	0	1	1	4	0.8	Pass
9. Squat Jump Takeoff Height	1	1	1	1	1	5	1	Pass
10. 5 meter sprint	1	1	1	1	1	5	1	Pass
11. 10 meter sprint	1	1	1	0	1	4	0.8	Pass
12. Volleyball Special T-Test	1	1	1	1	1	5	1	Pass

13. Standing serve speed test	1	1	1	1	1	5	1	Pass
14. Spike speed test	1	1	0	1	0	3	0.6	Pass
Part 3:Changing direction ability indicators								
15. 180º Change of Direction Speed(s)	1	1	1	1	1	5	1	Pass
16. T-shaped running	1	1	1	1	1	5	1	Pass

Appendix D
8-week training program schedule

Table 11 Experimental arrangements

Period	Pre-Test	The first training period				The second training period				Post-Test
Time	2024.11.13-11.17	2024.11.18-12.15				2024.12.16-2025.1.12				2025.1.13-1.19
Weekly		1	2	3	4	5	6	7	8	
content	1. Maximal force, 2. Explosive power, 3. Changing direction ability	1. Unilateral Training Group: Unilateral complex training 2. Bilateral Training Group: Bilateral complex training				1. Unilateral Training Group: Unilateral complex training 2. Bilateral Training Group: Bilateral complex training				1. Maximal force, 2. Explosive power, 3. Changing direction ability
Location	Physical Fitness Testing Center	Athletics Field and Strength Room				Athletics Field and Strength Room				Physical Fitness Testing Center

Table 12 Unilateral complex training content-Experimental group

The training courses in the first stage (weeks 1-4)					
Time	Type	Training sequence and content	Frequency	Intensity	Interval
15 min	Warm-up exercise	Hug knee and move forward; Hugging legs diagonally; Back cross lunge; Heel against hip-arm extended upwards; Lateral lunge movement; Balance stand; Backward lunge+rotation; Sumo style squat; Walk on all fours; The Greatest Stretching	1set, 5 times on each side	50%-70% HRmax	0
60 min	Unilateral complex training (resistance training + plyometric training).	Training content 1: Resistance training Training action 1: Resistance Bulgarian split squat (Back Squat) Training action 2: Resistance Unilateral Half-Squat (Back Squat) Training action 3: Resistance Unilateral Deadlift	4 set*4 times	85% 1RM	Rest for 2 min betwee n each set; Rest for 3 min betwee n each project
		Training content 2: Plyometric Training Training action 1: Unilateral Vertical Jump Training action 2: Unilateral Drop Jump Training action 3: Unilateral Hurdle Jump	4 set*7 times	100% (Overco me one's own body weight)	
15 min	Cool-down exercise	Stretching the hamstring muscles behind the thigh; Front thigh quadriceps stretch; Hip joint flexor muscle extension; Calf stretch; Gluteal muscle extension; Chest extension; Upper-Back Stretch; Shoulder extension	1set, 5 times on each side	30%-50% HRmax	0
The training courses in the second stage (weeks 5-8)					
Time	Type	Intervention sequence and content	Frequency	Intensity	Interval
15 min	Warm-up exercise	Warm-up exercise: Hug knee and move forward; Hugging legs diagonally; Back cross lunge; Heel against hip-arm extended upwards; Lateral lunge movement; Balance stand; Backward lunge+rotation; Sumo style squat; Walk on all fours; The Greatest Stretching	1 set, 5 times on each side	50%-70% HRmax	0
70 min	Unilateral complex training (resistance training +	Training content 1: Resistance training Training action 1: Resistance Bulgarian split squat (Back Squat) Training action 2: Resistance Unilateral Half-Squat (Back Squat)	5 set*5 times	85% 1RM	Rest for 2 min betwee n each set;

	plyometric training).	Training action 3: Resistance Unilateral Deadlift			Rest for 3 min betwee n each project
		Training content 2: Plyometric Training Training action 1: Unilateral Vertical Jump Training action 2: Unilateral Drop Jump Training action 3: Unilateral Hurdle Jump	5 set*10 times	100% (Overco me one's own body weight)	
15 min	Cool-down exercise	Cool-down exercise: Stretching the hamstring muscles behind the thigh; Front thigh quadriceps stretch; Hip joint flexor muscle extension; Calf stretch; Gluteal muscle extension; Chest extension; Upper-Back Stretch; Shoulder extension	1set, 5 times on each side	30%-50% HRmax	0

Table 13 Bilateral complex training content - Control group

The training courses in the first stage (weeks 1-4)					
Time	Type	Intervention sequence and content	Frequency	Intensity	Interval
15 min	Warm-up exercise	Hug knee and move forward; Hugging legs diagonally; Back cross lunge; Heel against hip-arm extended upwards; Lateral lunge movement; Balance stand; Backward lunge+rotation; Sumo style squat; Walk on all fours; The Greatest Stretching	1set, 5 times on each side	50%-70% HRmax	0
60 min	Bilateral complex training (resistance training + plyometric training).	Training content 1: Resistance training Training action 1 : Resistance Bilateral squat (Back Squat) Training action 2 : Resistance Bilateral Half-Squat (Back Squat) Training action 3 : Resistance Romanianl Deadlift	4set*4 times	85% 1RM	Rest for 2 min between each set; Rest for 3 min between each project
		Training content 2: Plyometric Training Training action 1 : Bilateral Vertical Jump Training action 2 : Bilateral Drop Jump Training action 3 : Bilateral Hurdle Jump	4set*7 times	100% (Overcoming one's own body weight)	
15 min	Cool-down exercise	Stretching the hamstring muscles behind the thigh; Front thigh quadriceps stretch; Hip joint flexor muscle extension; Calf stretch; Gluteal muscle extension; Chest extension; Upper-Back Stretch; Shoulder extension	1set, 5 times on each side	30%-50% HRmax	0
The training courses in the second stage (weeks 5-8)					
Time	Type	Intervention sequence and content	Frequency	Intensity	Interval
15 min	Warm-up exercise	Warm-up exercise:Hug knee and move forward; Hugging legs diagonally; Back cross lunge; Heel against hip-arm extended upwards; Lateral lunge movement; Balance stand; Backward lunge+rotation; Sumo style squat; Walk on all fours; The Greatest Stretching	1set, 5 times on each side	50%-70% HRmax	0
70 min	Bilateral complex training (resistance	Training content 1: Resistance training Training action 1 : Resistance Bilateral squat (Back Squat) Training action 2 : Resistance Bilateral	5set*5 times	85% 1RM	Rest for 2 min between each set;

	training + plyometric training).	Half-Squat (Back Squat) Training action 3 : Resistance Romanianl Deadlift			Rest for 3 min between each project
		Training content 2: Plyometric Training Training action 1 : Bilateral Vertical Jump Training action 2 : Bilateral Drop Jump Training action 3 : Bilateral Hurdle Jump	5set*10 times	100% (Overcoming one's own body weight)	
15 min	Cool-down exercise	Cool-down exercise: Stretching the hamstring muscles behind the thigh; Front thigh quadriceps stretch; Hip joint flexor muscle extension; Calf stretch; Gluteal muscle extension; Chest extension; Upper-Back Stretch; Shoulder extension	1set, 5 times on each side	30%-50% HRmax	0

Appendix E
Test and Training Photo

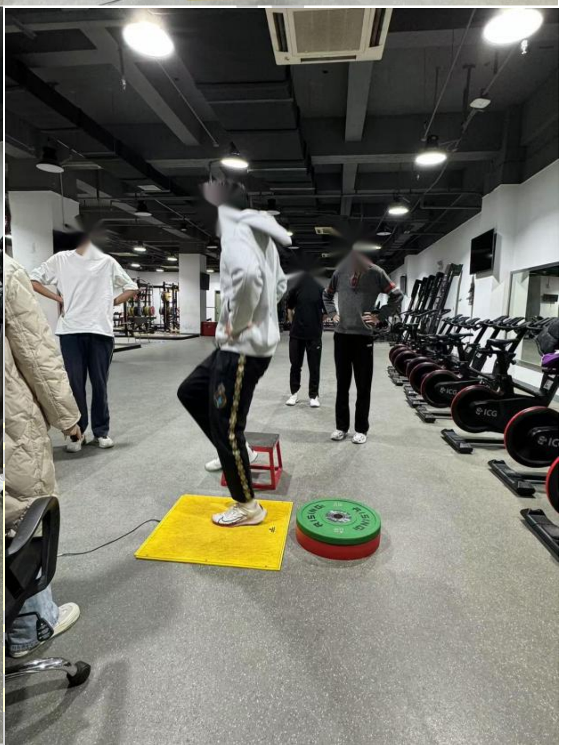


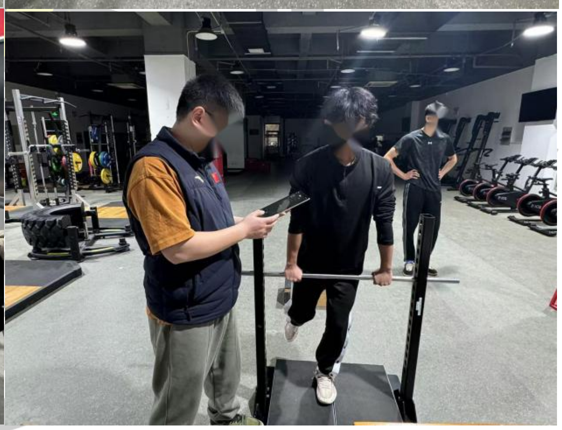


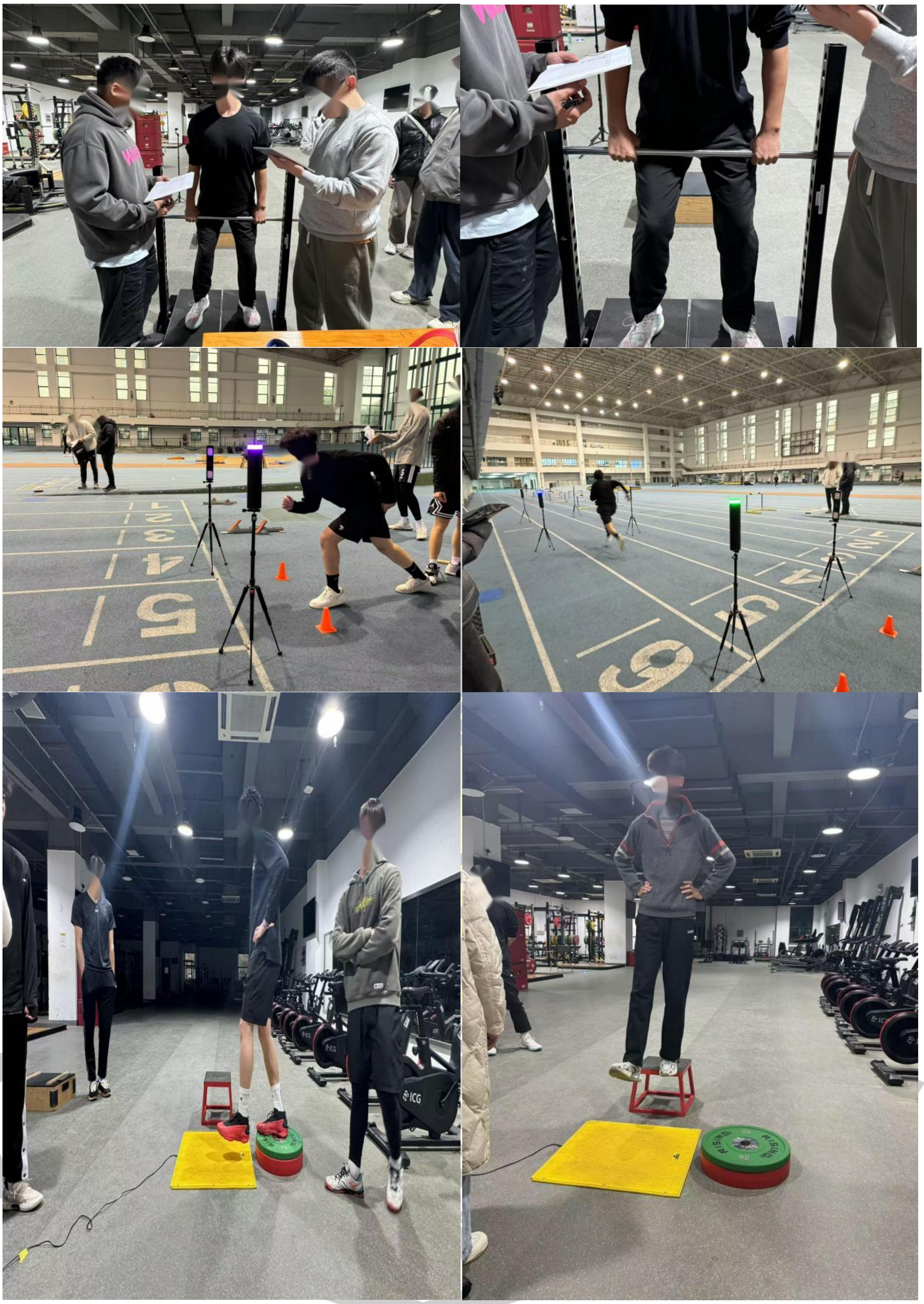

04

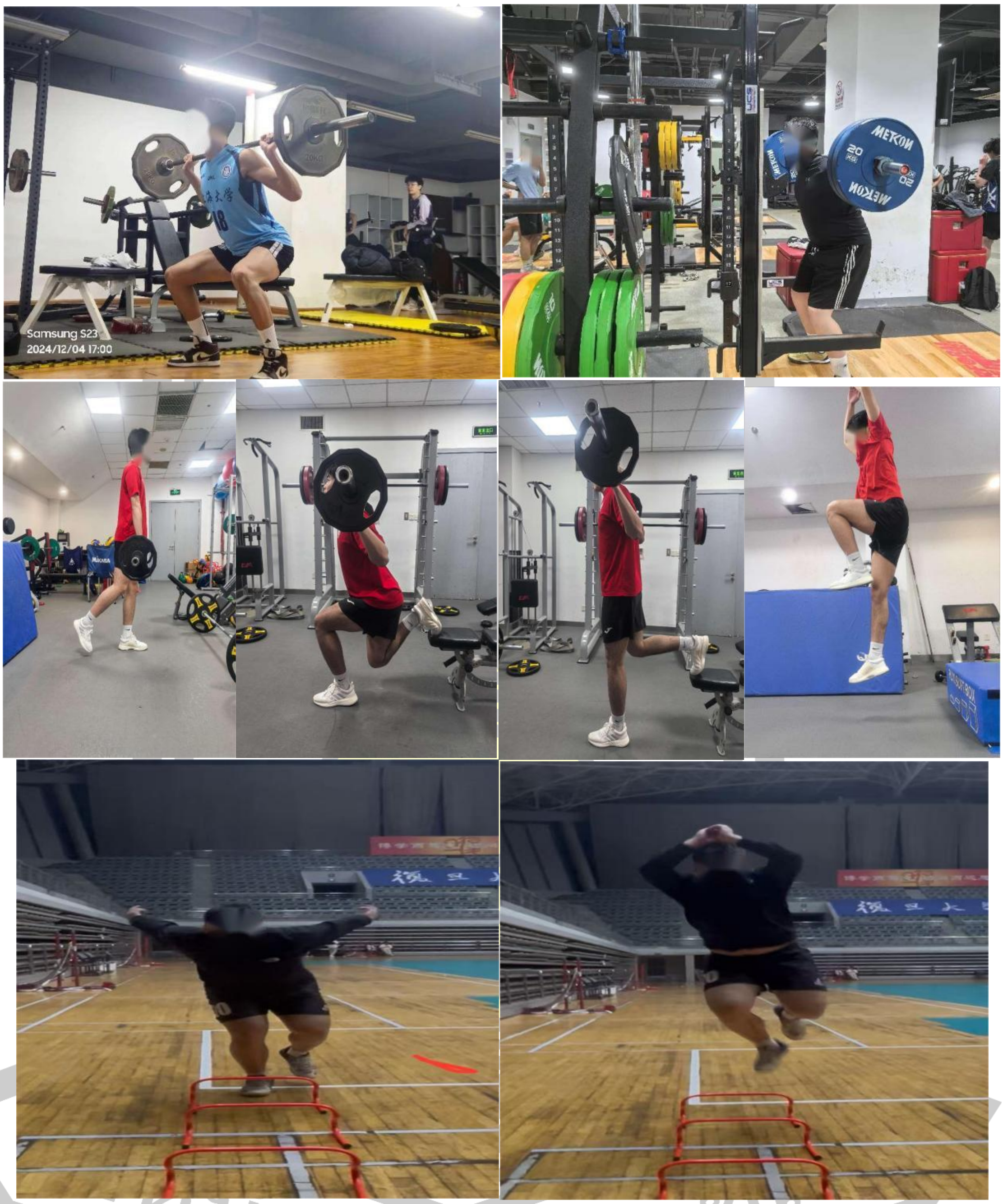








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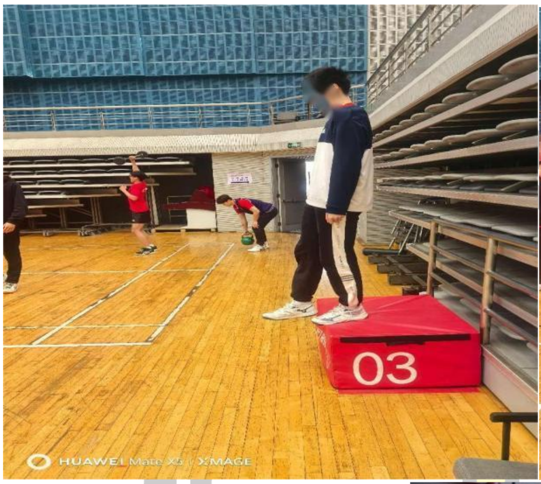
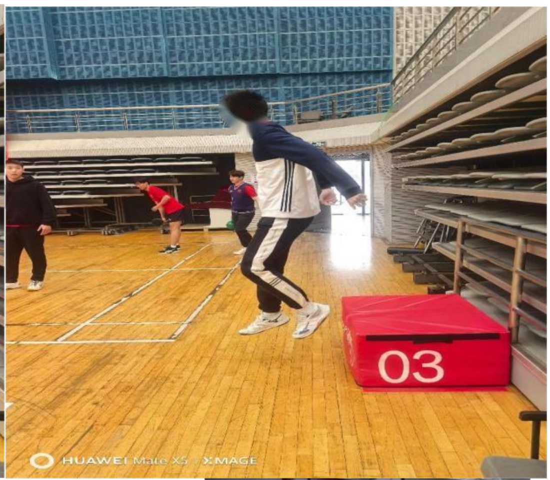

03
HUAWEI Mate X5 | XMAGE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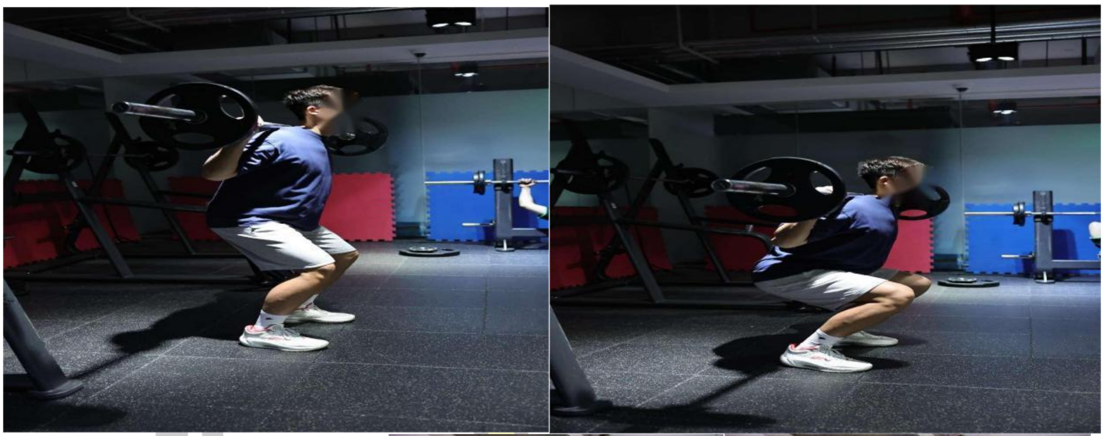
HUAWEI Mate X5 | XMAGE


PLYO SOFT BOX



BIOGRAPHY

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