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Article

The impact of single-leg stability training on injury reduction in throwing athletes

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Abstract: In the realm of throwing sports, athlete stability and coordination are crucial for achieving optimal performance and minimizing the risk of injury. From a biomechanical perspective, single-leg stability training has been demonstrated to enhance an athlete's dynamic balance, improve joint stability, and increase the coordination and reaction speed of muscle groups. These physiological and functional enhancements for throwing athletes translate to better body control during high-speed movements and explosive power bursts, thereby reducing the incidence of sports injuries caused by imbalance or instability. This review offers insights into the potential benefits of single-leg stability training for reducing sports injuries among throwing athletes. It highlights the crucial role of such training in enhancing sports efficiency, preventing injuries, and improving overall performance. Ultimately, this paper proposes future research directions, including the application of advanced biomechanical analysis tools to customize individualized training programs and the validation of the effectiveness and sustainability of these strategies through long-term follow-up studies. The findings of this review not only provide theoretical support for the training practices of throwing athletes but also establish a solid foundation for further research in the field of sports science.

Keywords: biomechanics; single-leg stability training; sports injury prevention; throwing athletes

1. Introduction

In the highly competitive realm of sports, the performance of throwing athletes is critical; however, the issue of sports injuries they encounter should not be overlooked. In recent years, advancements in sports medicine and biomechanics have led to a clearer understanding of the injuries sustained by throwing athletes. These injuries primarily affect the rotator cuff, elbow, back, and lower extremities, particularly those resulting from overuse and improper loading of the shoulder and knee joints [1,2]. The persistently high incidence of these injuries is largely influenced by factors such as the standardization of technical movements, muscle strength and balance, the structuring of training loads, and individual differences among athletes.

The complexity of the throwing motion necessitates that athletes possess a high degree of technical accuracy. Any minor technical deviation can result in an uneven distribution of biomechanical loads, potentially leading to injury [3]. Throwing athletes must develop significant muscular strength to support high-speed movements; imbalances in muscular strength can compromise joint stability [4]. Both overtraining and undertraining can result in injuries among athletes; therefore, a well-structured training program is essential for injury prevention.

The role of single-leg stability training in sports injury prevention has gained increasing emphasis as a method specifically designed to enhance lower limb strength and balance [5]. This type of training improves athletes' stability and reaction speed during dynamic movements by simulating the single-leg support position commonly encountered in sports, thereby effectively reducing injuries caused by imbalance. On one hand, targeted training can enhance the strength of the thigh, calf, and hip muscles, providing stable support for the throwing movement [6]. On the other hand, single-leg training improves athletes' muscle control, particularly in the nondominant leg, which can help reduce improper movements in sports [7]. Most importantly, single-leg stability training enhances athletes' movement coordination and decreases the risk of injury caused by uncoordinated movements [8,9].

This study aims to thoroughly investigate the impact of single-leg stability training on the prevention of sports injuries among throwing athletes, as well as its underlying mechanisms. By analyzing the effects of single-leg stability training on the biomechanical characteristics of these athletes, we aim to elucidate the mechanisms involved in injury prevention. We propose a framework for single-leg stability training grounded in biomechanical principles to offer scientific guidance for the training of throwing athletes. This review will provide an empirical evidence base for the training and rehabilitation of throwing athletes, assisting both athletes and coaches in the scientific development of training programs.

2. Method

Literature searches were conducted using PubMed, Google Scholar, Elsevier ScienceDirect, and Web of Science. The search strategy employed the following terms: "thrower," "single-leg stability training," "sports injury," "sports injury prevention," "biomechanics," "biomechanics and single-leg stability training," "single-leg stability training and thrower," "thrower and sports injury," "biomechanics and sports injury and thrower," among others.

3. Biomechanical basis of single-leg stability training for hurlers

In throwing movements, athletes must generate high-speed rotation and propulsion through a series of complex muscle coordination and joint activities. Single-leg stability training is a specialized training method designed to enhance the overall capabilities of throwing athletes while in a single-leg support position, including balance, strength, and coordination.

3.1. Balancing ability

Single-leg stability training challenges a throwing athlete's ability to maintain body balance while in a single-legged supported position by simulating an unstable environment similar to that encountered in the sport [10]. This training modality is deeply rooted in several key biomechanical principles (**Figure 1**). One of these principles is core muscle activation; single-leg training effectively engages the core muscles, including the abdominal, back, and pelvic floor muscles, which are essential for maintaining body stability and balance [11].

At the same time, the role of the calf muscles should not be overlooked, particularly the tibialis anterior and gastrocnemius muscles, which are significantly activated during single-leg stance. These muscles play a crucial role in maintaining balance by fine-tuning the body's movements [12]. Importantly, single-leg stability training also enhances the athlete's neurofeedback mechanisms, allowing for a more acute perception of changes in the position of the center of gravity. This heightened awareness enables the athlete to make rapid adjustments, thereby improving overall balance control.

Figure 1. Subject performing the posterior reach component of the star excursion balance test (SEBT). adapted with permission from ref. [5]. copyright 2007 Elsevier.

3.2. Strengthening of forces

Single-leg stability training has been shown to significantly enhance muscle strength in the lower extremities, which is particularly crucial for throwing athletes. The gluteus maximus plays a vital role in the muscle-strengthening process for these athletes. As the largest muscle group in the lower body, it not only provides essential stability but also contributes critical propulsive force during single-leg training [13]. Similarly, strengthening the quadriceps is a key focus of training, as this muscle group is responsible for knee extension movements. Single-leg training effectively enhances its explosive power during throwing actions [14]. The strength of the calf muscles, particularly the triceps surae, should not be overlooked, as they are essential for maintaining ankle stability and generating propulsive force. Single-leg stability training is an effective method for improving their function [5]. Collectively, the increased strength of these muscle groups establishes a solid foundation for throwing athletes, thereby enhancing their overall athletic performance.

3.3. Neuromuscular control

Single-leg stability training significantly enhances the neuromuscular control of throwing athletes during single-leg support, which is crucial for both athletic performance and injury prevention. Specifically, through single-leg training, athletes can control their body movements more precisely, ensuring that proper technical postures are maintained throughout the movement. This effectively reduces the occurrence of incorrect movements, thereby improving the stability and efficiency of technical actions [15]. Furthermore, excellent neuromuscular control aids in recognizing and mitigating instability in sports, directly lowering the risk of sports-related injuries [16] and providing a safer performance platform for athletes. Consequently, single-leg stability training not only optimizes athletes' technical performance but also equips them with effective injury prevention strategies.

3.4. Biomechanical optimization

Single-leg stability training effectively optimizes the biomechanics of throwing athletes by adjusting the distribution of force lines, thereby reducing the overload on joints and soft tissues. Specifically, this type of training enables athletes to achieve a more rational distribution of forces during throwing, which alleviates stress on joint surfaces and decreases the risk of joint injuries [17]. Long-term engagement in single-leg stability training fosters functional adaptations in the athlete's body, allowing it to better meet the diverse demands of the sport. This not only enhances athletic efficiency but also improves safety [18]. In conclusion, the biomechanical principles underlying single-leg stability training provide an effective training tool for throwing athletes, aiming to comprehensively enhance athletic performance while effectively preventing injuries by improving balance, strengthening muscles, enhancing neuromuscular control, and optimizing biomechanical properties.

4. Methods and tools for single-leg stability training

4.1. Definitions and classifications

Single-leg stability training is a specialized training method designed to address the specific needs of athletes. Its primary goal is to enhance an athlete's overall performance while in a single-legged support position, focusing on three key aspects: balance, strength, and coordination [19]. This training approach, which requires the athlete to support their body weight on one leg, is particularly beneficial for throwing athletes [20]. It effectively improves stability and performance during physical activity, thereby reducing the risk of sports-related injuries [21]. Based on its objectives, single-leg stability training can be categorized into three types: static stability training, dynamic stability training, and advanced stability training.

Static stability training primarily focuses on enhancing athletes' balance abilities through single-leg support exercises. Specifically, athletes are required to maintain a fixed position on one leg for as long as possible, which helps improve the endurance and balance of the leg muscles [22]. Additionally, core strength training is a crucial component of static stability training, as it enhances athletes' core stability by engaging the abdominal, back, and pelvic muscles while in a single-legged support position [23].

Dynamic stability training, in contrast, requires athletes to execute a series of dynamic movements supported by a single-leg to enhance strength, coordination, and explosiveness [24]. This training regimen includes single-leg jumps, landing stabilization exercises, and transition training. Single-leg jumping develops the athlete's leg strength and explosive power, while landing stabilization quickly restores balance after jumping and enhances stability during landings [25]. Furthermore, training for rapid directional transitions improves athletes' coordination and agility.

Finally, advanced stability training builds upon static and dynamic stability training to further enhance the difficulty and complexity of the regimen [26]. Athletes engage in single-leg exercises on unstable surfaces, such as foam mats and balance balls, to improve muscle control and stability. Simultaneously, while executing complex movements like throwing and catching a ball, athletes must maintain single-leg support to enhance stability during actual performance [27]. This training method integrates the fixed postures of static stability training, the dynamic movements of dynamic stability training, and more challenging advanced movements to comprehensively improve athletes' single-leg stability.

4.2. Training methods and tools

4.2.1. One-legged squat

As a fundamental yet effective method for single-leg stability training, the single-leg squat significantly enhances lower limb strength and joint stability in athletes [28]. In a one-legged support position, the athlete performs a squatting motion that not only strengthens the muscles of the lower limbs but also improves the stability of the knee and ankle joints [29]. During this training, athletes should select a fixed point as a visual reference to ensure that their body maintains a straight posture. They should then slowly lower themselves into a squat until their thighs are parallel to the ground, followed by a forceful return to a standing position. Throughout the training process, it is crucial for athletes to keep the knee in a neutral position, avoiding inversion or eversion, to prevent improper pressure distribution and reduce the risk of sports injuries [30]. By emphasizing precise movement control, single-leg squat training not only enhances muscle functionality but also establishes a solid foundation for the athlete's overall performance.

4.2.2. Single-leg hard pull

As a training tool focused on the posterior chain muscle groups of athletes, single-leg pulling serves as an integrated exercise for the back, hips, and posterior leg muscles [31]. In this type of training, athletes perform a challenging pulling action while standing on one leg. This approach not only effectively enhances muscle stability and strength but also improves overall body coordination. Specifically, the athlete stands on one leg with the other leg slightly flexed to maintain balance, while holding dumbbells or a barbell in both hands, ensuring that the back remains straight. During the execution of the movement, the athlete must squat slowly until the body is parallel to the ground, with trunk stability being crucial to prevent excessive bending or rotation [32]. Through these movements, athletes not only engage the posterior chain muscle groups but also enhance balance and core stability during single-leg bracing, ultimately improving performance and reducing the overall risk of injury.

4.2.3. One-legged box jumps

Single-leg box jump training is a comprehensive training method that combines strength and explosive power, aiming to enhance athletes' stability during landing. This is achieved by jumping onto a box with one leg and landing smoothly [33,34]. To perform this training, athletes must first select a box of appropriate height and then execute a jump onto the box using one leg. Throughout this process, the athlete should not only generate strong explosive force but also maintain control of their body in the air to ensure a smooth landing. Special attention must be given to knee flexion and ankle stability upon landing, as both are crucial for minimizing impact [35]. Through this training, athletes can enhance their leg muscle strength, improve their jumping skills, and refine their body control during landing, ultimately leading to better performance in competitive sports.

4.2.4. Unstable plane training

Performing single-leg training on an unstable surface, such as a balance mat or a wobble board, not only significantly increases the difficulty of the exercise but also compels the athlete to engage more muscle fibers to maintain body balance [36]. In this challenging environment, athletes perform a series of movements, including standing on one leg, squatting, and jumping, which not only test muscle control but also enhance coordination [37]. By training in a dynamic state, athletes can more effectively improve their muscle fine-tuning abilities, which, in turn, enhances their capacity to adapt to variable environments. This type of training has a substantial impact on improving athletes' performance when confronted with complex situations during competition or training, enabling them to be more stable and flexible in addressing various challenges in the arena.

4.3. Training principles

4.3.1. Principle of progressivity

The principle of progression in single-leg stability training dictates that the development of the training program should advance from simple to complex and from stable to unstable, thereby gradually increasing the training difficulty [38]. In the initial stage, athletes should begin with basic single-leg balance exercises and progressively transition to dynamic stability training [39]. As the athlete's balance improves, the training can incorporate single-leg maneuvers on unstable surfaces, as well as advanced stability training that includes throwing maneuvers. This progressive approach to training enables athletes to adapt gradually and helps prevent potential injuries that may arise from making excessive jumps in training difficulty.

4.3.2. The principle of personalization

The principle of individualization emphasizes that training programs should be tailored to each athlete, taking into account factors such as age, gender, skill level, and injury history. Younger athletes may focus more on developing basic strength and balance, while more experienced athletes may require advanced stability training [40]. Gender differences can also influence the design of training programs; for instance, female athletes may need special attention to prevent ACL injuries [41]. For athletes with a history of injury, training programs should incorporate specific rehabilitative stability training to facilitate recovery and prevent recurrence [42].

4.3.3. Systemic principles

The principle of systematicity dictates that single-leg stability training must be implemented as a continuous and coherent process to establish a comprehensive training system [43]. This training should occur throughout the entire season, encompassing various phases such as pre-season, mid-season, and post-season, to ensure the ongoing enhancement of athletes' stability skills. Furthermore, the training system should be integrated with other physical and technical training components to create a holistic training program [44].

4.3.4. Security principles

The principle of safety is a fundamental component of single-leg stability training, designed to ensure both the safety of the training environment and the proper execution of training methods [45,46]. The training area should be level and free of obstacles, and the equipment utilized must be stable and reliable to minimize the risk of accidental injuries during training. Coaches should ensure that athletes perform each training maneuver correctly to prevent sports injuries resulting from technical errors [47]. Additionally, regular supervision and evaluation of training outcomes are essential measures to maintain training safety.

Table 1. Effects of single-leg stability training on injury reduction in throwing sports.

Perspective	Advantages of single-leg stability training	Necessity and applicability	Potential challenges or limitations	Ref.
Improved joint stability	Enhance the stability of joints, including the knees, hips, and ankles, to reduce sports injuries resulting from joint instability.	Ioints experience significant stress during throwing sports, and single-leg training is effective in preventing injuries.	Individualized training programs are essential to prevent both overtraining and undertraining.	[48,49]
Builds muscle strength and coordination	Enhances coordination among muscle groups and reaction time, thereby improving overall athletic performance.	Throwing requires the coordination of multiple muscle groups, and single-leg training enhances this synergy.	Training intensity and frequency must be carefully regulated; otherwise, recovery may be compromised.	[50]
Improved neuromuscular control	Enhanced athletes' ability to respond swiftly to sudden changes.	Neuromuscular control is essential for executing motor skills and preventing sports injuries.	Need professional guidance	[51]
Dynamic balance	Significantly improves an athlete's dynamic balance and enhances stability during complex movements.	It is essential for throwing athletes to maintain balance control during high-speed movements and explosive power bursts.	It may take longer to adapt, and some athletes may be at an increased risk of injury due to poor technique.	[52]
Training adaptations	The training difficulty can be adjusted to match the athlete's skill level, making it suitable for athletes of all abilities.	This program is suitable for athletes of all levels, particularly those at an advanced level.	Beginners may require more time to adapt, and they may experience increased psychological pressure during the initial stages of training.	[53]
Psychological factor	Enhances the athlete's self-confidence and concentration.	The positive impact on the psychological development of throwing athletes.	Gradual adaptation may be necessary, as psychological stress can increase at the beginning of training.	[54]
Diversity of training methods	Versatile training methods that can be easily integrated into daily routines.	Effective training requires the collaborative efforts of both coaches and athletes.	Professional guidance and monitoring equipment are essential to prevent technical errors.	[55]
Reduced laterality	Enhance the stability and athletic performance of the non-dominant leg while reducing body asymmetry through unilateral training.	It is essential for throwing athletes to minimize sports injuries related to laterality.	It requires long-term persistence and is challenging to achieve significant improvements in laterality in the short term.	[41]

5. Effects of single-leg stability training on injury reduction in throwing sports

5.1. Improvement of joint stability

5.1.1. Knee stability

Joint stability is essential for maintaining proper joint function in sports and is particularly important for throwing athletes. Single-leg stability training significantly contributes to enhancing joint stability (**Table 1**). The knee, one of the largest joints in the human body, plays a crucial role in athletic performance and injury risk. Its stability is of paramount importance in sports [48].

Single-leg stability training enhances knee stability through multiple mechanisms [49]. First, this training focuses on strengthening key muscle groups surrounding the knee joint, including the quadriceps, hamstrings, and gluteus maximus, all of which are essential for maintaining knee stability. Second, the exercises improve muscle coordination, ensuring that the trajectory of the knee joint is effectively controlled during physical activity, thereby preventing excessive displacement or inappropriate loading. Finally, movements such as single-leg squats and single-leg deadlifts simulate the single-leg load-bearing conditions encountered in sports [56]. This not only enhances knee joint stability during athletic performance but also helps reduce the risk of knee injuries in competitive settings [57]. Therefore, single-leg stability training is an effective strategy for athletes to prevent injuries and improve knee stability.

5.1.2. Hip stability

Hip stability plays a crucial role in the entire kinetic chain, and its effectiveness directly impacts athletic performance and injury risk [58]. Single-leg stability training is significant for enhancing hip stability in two primary ways. This training focuses on strengthening the smaller muscle groups surrounding the hip joint, particularly the gluteus medius and gluteus minimus, which are essential for maintaining hip stability and controlling pelvic position. Through one-legged jumping and balancing exercises, athletes can improve the stability and control of the hip joint during dynamic movements [59]. This not only enhances athletic performance but also effectively reduces the risk of injuries associated with hip joint instability, which can lead to lower limb sports injuries [60]. Therefore, single-leg stability training not only fortifies hip joint stability but also provides athletes with a more robust athletic foundation, resulting in improved performance and a lower risk of injury across various sports.

5.1.3. Ankle stability

In throwing sports, the ankle joint experiences significant stress during jumping and rapid directional changes. Therefore, single-leg stability training is crucial for enhancing the stability of this joint [61]. This training method effectively improves ankle stability during weight-bearing and dynamic movements by targeting the strengthening of calf muscles, including the soleus and tibialis anterior [62]. Additionally, single-leg stability training enhances ankle balance, which is essential for reducing the risk of sprains and other injuries related to uneven surfaces or sudden movements [63]. Collectively, single-leg stability training improves joint stability by increasing the strength and coordination of the muscles surrounding key joints, thereby mitigating the risk of sports injuries at their source. For throwing athletes, this training approach not only enhances athletic performance but also serves as a vital strategy for injury prevention.

5.2 Enhance muscle strength and coordination

5.2.1. Increase in muscle strength

Muscle strength and coordination are the two fundamental pillars that underpin a throwing athlete's physical stability during competition. Single-leg stability training plays a crucial role in enhancing both of these areas. Through a series of well-designed strength-training exercises, single-leg stability training significantly improves athletes' lower limb muscle strength [64]. For instance, exercises such as single-leg deep squats and single-leg deadlifts specifically target the major muscle groups in the lower limb, including the quadriceps on the anterior side of the thigh, the hamstrings on the posterior side, and the gluteus maximus [50]. These exercises not only promote an increase in muscle volume and density but also enhance muscle recruitment, enabling athletes to maintain body control more effectively during high-speed movements [65]. As muscle strength increases, athletes develop a firmer base of support, which is particularly important during strenuous exercise or sudden force generation. This stability effectively reduces the risk of joint instability and injury due to insufficient strength. Therefore, single-leg stability training serves not only as a method for building muscle strength but also as a crucial strategy for preventing sports injuries.

5.2.2. Improvement of muscle coordination

The importance of muscle coordination—defined as the ability of muscles to work in concert during movement—cannot be overstated for throwing athletes engaged in complex movements [66]. Through single-leg balance and agility exercises, such as single-leg standing turns and single-leg jumps, athletes are required to quickly adjust their body positions while maintaining stability. This process significantly enhances intermuscular synergistic function [67]. Such coordination training not only helps athletes maintain proper technique when executing throwing movements but also effectively reduces the risk of sports injuries caused by uncoordinated movements or errors. Furthermore, good muscle coordination is crucial for improving athletes' reaction speed and movement efficiency, which often become key determinants of victory in highly competitive events [68]. Therefore, single-leg balance and agility exercises serve as a foundation for enhancing athletic performance and are essential for ensuring athletes achieve optimal performance in competitions.

5.3. Improved neuromuscular control

The significance of neuromuscular control, which is essential for executing motor skills and preventing sports injuries, cannot be overlooked for throwing athletes [69]. Implementing single-leg stability training in this context offers an effective method to improve athletes' neuromuscular control abilities.

5.3.1. Reflective conditioning enhancement

Single-leg stability training significantly enhances the reflex regulation of athletes by engaging them in unstable conditions [51]. Training on unstable surfaces, such as standing on one leg on a balance mat or performing dynamic movements on a wobble board, compels the athlete's nervous system to rapidly adjust muscle activity to maintain balance. This type of training not only improves athletes' ability to respond swiftly to sudden changes but also ensures they can make timely and accurate movement adjustments when faced with unforeseen situations during competition or training, effectively reducing the risk of injury [70]. Enhanced reflex regulation is essential for athletes to maintain body control during high-speed movements, which minimizes falls and injuries caused by imbalance, thereby improving the overall safety of athletic performance.

5.3.2. Optimization of muscle activation sequence

The correct sequence of muscle activation is crucial for the accuracy and efficiency of throwing techniques, and single-leg stability training significantly contributes to this aspect. By engaging in single-leg stability training, athletes can learn and master the appropriate sequence of muscle activation in a more comprehensive manner, ensuring that the relevant muscle groups are recruited systematically during the execution of the throwing motion [71]. This type of training not only helps eliminate unnecessary muscle activity and reduce energy expenditure, thereby enhancing performance, but also optimizes the muscle activation sequence and effectively prevents sports injuries, such as excessive joint stress or muscle strains caused by improper activation [72].

5.4. Reducing the risk of sports injuries

5.4.1. Reduction of fall risk

Balance and coordination are two essential factors in maintaining an athlete's stability in sports, and single-leg stability training plays a significant role in enhancing these abilities. Through single-leg balance and agility training, athletes can maintain stability on unstable surfaces, which not only reduces the risk of falling due to loss of balance during competition or training but also improves adaptability on irregular surfaces [73,74]. For throwing athletes, this training enables them to maintain better body control and ensure technical accuracy and efficiency in complex competitive environments.

5.4.2. Joint sprain risk reduction

Joint stability plays a crucial role in preventing joint sprains, and single-leg stability training effectively reduces the risk of these injuries by enhancing the strength and coordination of the muscles surrounding the joint [75]. This stability is particularly vital in sports that involve rapid changes in direction and jumping, such as the starting and launching phases of throwing events [76]. Single-leg stability training not only improves joint stability during multidirectional movements but also decreases the incidence of sprains resulting from joint instability. This approach provides athletes with a safer and more efficient training environment, as well as enhanced competition security [77]. Through this training, athletes can maintain joint stability during high-intensity exercise and avoid injuries caused by sudden movements, which is essential for sustaining long-term health throughout their athletic careers.

5.4.3. Reduced risk of muscle strains

As one of the most prevalent types of injuries in sports, preventive measures for muscle strains are essential. Single-leg stability training effectively reduces the risk of muscle strains by enhancing both muscle strength and neuromuscular control [78]. This training enables the muscles to better withstand the stresses associated with high-intensity exercise by improving their strength and elasticity. Additionally, enhanced neuromuscular control ensures proper recruitment and coordination of the muscles during exercise, which helps minimize strains caused by overstretching or improper muscle usage [79].

6. Single-leg stability training in throwing athletes

6.1. Development of training programs

6.1.1. Frequency of training

The setting of training frequency is central to the development of an effective training program, and its rationale plays a crucial role in both training effectiveness and athlete recovery. Factors influencing the determination of training frequency include individual differences among athletes, such as age, gender, and physical condition, as well as training experience, seasonal cycles, and overall training load [52]. For beginner-level athletes, it is recommended to incorporate single-leg stability training 2 to 3 times per week, performing 8 to 12 repetitions each session. As their training progresses, the number of sets can be gradually increased to between 4 and 6, while the number of repetitions per set can be appropriately reduced to between 6 and 8. Recovery intervals are essential for training effectiveness and athlete recovery. In single-leg stability training, inter-set intervals are typically recommended to be between 1 to 2 min. It is also important to ensure adequate rest between training days to prevent the accumulation of muscle fatigue on consecutive days [41]. Furthermore, the monitoring and adjustment of training frequency are equally important; adjustments should be made promptly based on the athlete’s physiological and psychological health status, training feedback, and phase assessment results to maintain the appropriateness and effectiveness of the training regimen [80].

6.1.2. Intensity of training

The rationalization of training intensity is essential for enhancing athletes’ performance while minimizing the risk of injuries. To achieve this objective, training intensity should adhere to the principle of gradual progression from low to high levels, thereby promoting athlete adaptation and reducing the likelihood of injury [81]. This progressive approach not only enables athletes to gradually confront the challenges of training but also enhances overall training effectiveness [82]. Training intensity should be carefully calibrated, taking into account the athlete’s strength level, technical proficiency, and physical recovery capacity to ensure that training is individualized to meet the specific needs of each athlete [53]. Through meticulous management of training intensity, athletes can minimize the risk of injury while continuously improving their skills and performance.

6.1.3. Training cycle

The planning of the training cycle must be closely aligned with the athlete’s annual training program to ensure that long-term goals are achieved in a systematic manner. In long-term planning, the training cycle should encompass a preparation period, a competition period, and a recovery period, with specific training objectives and requirements established for each phase [83,84]. As the athlete’s status and competition demands evolve, the content and focus of single-leg stability training should be adjusted accordingly within each cycle to align with the changing training objectives [85]. Combining unilateral jumping variations (e.g., single-leg box jumps, single-leg bounces, and single-leg depth jumps) with other frequently utilized single-leg exercises can significantly enhance a throwing athlete's stability, strength, explosiveness, coordination, and agility. This comprehensive approach effectively reduces the risk of sports injuries. The transition between different training cycles should be seamless and fluid, which not only helps to prevent drastic fluctuations in training status but also maintains the athlete's physical condition while minimizing the risk of overexertion and injury [86]. Through meticulous cycle planning and transition management, athletes can be assured of maintaining their optimal condition throughout the annual training process and making consistent progress toward their established goals.

6.2. Evaluation of the effectiveness of training

6.2.1. Functional testing

Functional tests are essential tools for evaluating the effectiveness of single-leg stability training, as they provide objective data regarding athletes' performance capabilities. These tests should comprehensively address multiple dimensions, including balance, single-leg jumping power, and agility. Balance assessments, such as the Star Excursion Balance Test (SEBT) and the single-leg standing test, are specifically designed to evaluate athletes' stability under both static and dynamic conditions [54]. Single-leg jumping power tests, including the single-leg long jump and vertical jump, quantify explosive power on one leg. In contrast, agility tests, such as the Illinois Agility Test and the *T*-Test, focus on measuring the ability to change direction rapidly [87]. The collected test data should undergo statistical analyses, including descriptive statistics, correlation analysis, and hypothesis testing [88]. These analyses help quantify the changes observed before and after training, assess the significance of the training effects, and provide a scientific basis for adjusting the training program. Additionally, the results of functional tests must be analyzed comprehensively in conjunction with athletes' self-reports, coaches' observations, and sports performance data [89]. This multidimensional assessment method can more comprehensively reflect the effects of single-leg stability training and provide a solid scientific foundation for optimizing the training program.

6.2.2. Evaluation of athletic performance

Sports performance evaluation serves as a crucial indicator of training effectiveness for throwing athletes. The impact of single-leg stability training must be comprehensively assessed through multiple dimensions. Performance indicators include throwing distance, throwing speed, and technical score, which not only directly reflect the athlete's explosive power and technical efficiency but also the accuracy and fluidity of their movements [90]. To accurately assess the long-term effects of training, it is essential to conduct long-term tracking of athletes' performance, which includes regular testing and documentation of competition results. This approach allows for the observation of cumulative and continuous improvements resulting from training. Long-term tracking data helps identify correlations between training patterns and athletic performance, providing a solid foundation for the strategic planning of training programs [55]. Analyzing game performance should be integrated with the training cycle and competition outcomes to evaluate athletes' technical execution, decision-making abilities, and capacity to manage stress during games. This analysis offers practical guidance for the adjustment and optimization of training methods.

6.2.3. Injury incidence statistics

To gain a deeper understanding of the role of single-leg stability training in reducing sports injuries, it is essential to establish a systematic method for collecting injury incidence statistics. A comprehensive injury recording system serves as the foundation for evaluating the effectiveness of training programs. This system should meticulously document detailed information on the type of injury, time of occurrence, location of the injury, recovery process, therapeutic measures, and potential causative factors [91]. These data not only help identify patterns of injury and associated risk factors but also provide a crucial reference for adjusting training programs. Based on this information, the potential impact of single-leg stability training on reducing injury incidence can be assessed through statistical analysis of the injury records.

Risk assessment should encompass a comparison of data collected before and after the training intervention, along with an analysis of the differences among various training groups. Such an analysis can help quantify the extent to which training reduces the risk of injury and provide a scientific foundation for future training and prevention strategies [92]. Furthermore, comparing injury incidence before and after training is crucial for evaluating the preventive effects of single-leg stability training. This before-and-after analysis should take into account the injury records of the same group of athletes prior to and following the implementation of single-leg stability training, as well as the incidence of injuries in comparison to a control group [93]. Through this meticulous comparison, the actual effectiveness of single-leg stability training in preventing specific types of sports injuries can be assessed more accurately, thereby offering more precise guidance for sports training and health management.

7. Outlook

7.1. Application of new technologies

The incorporation of emerging technologies signifies a revolution in single-leg stability training. The rapid development of wearable technologies, such as smart clothing, sports trackers, and strength monitoring devices, is increasingly becoming a powerful tool for athletes and coaches to assess performance and biomechanical parameters. These technological advances not only enable more accurate assessments of training outcomes but also facilitate immediate adjustments to training strategies, significantly enhancing training efficiency and reducing the risk of injury.

The application of virtual reality (VR) technology in single-leg stability training introduces a novel training paradigm. VR technology can create simulated sports environments and scenarios, providing athletes with an immersive training experience [94,95]. Conducting single-leg stability training in this safe virtual environment not only enhances the enjoyment of training but also allows athletes to refine their skills while minimizing the risk of injury in actual sports. This, in turn, improves the overall effectiveness of the training.

7.2. Intensive biomechanical research

As biomechanics research advances, single-leg stability training is increasingly supported by scientific theories. The application of high-speed camera technology in movement analysis allows for the precise capture of subtle movements exhibited by athletes during training and competitions. This innovation paves the way for a more in-depth examination of the technical aspects of single-leg stability training. By utilizing high-speed cameras, researchers can accurately identify movement deficiencies and subsequently offer targeted recommendations for improvement, thereby enhancing the relevance and effectiveness of training [96]. Furthermore, the implementation of a 3D motion capture system provides comprehensive data support for studying dynamic balance and force transfer in single-leg stability training. This system meticulously records an athlete's trajectory in three-dimensional space, and the resulting data aids researchers in gaining a deeper understanding of training effects and injury mechanisms, thus establishing a crucial scientific foundation for optimizing training methods [97]. The combined use of these technologies not only fosters the theoretical advancement of single-leg stability training but also offers more precise guidance for practical training applications. Reason: Improved clarity, vocabulary, and technical accuracy while maintaining the original meaning.

7.3. Exploration of personalized training programs

The development of personalized training programs represents a significant trend in the future of athletic training. By conducting in-depth analyses of athletes' biomechanical parameters, we can create more tailored training programs that address the specific needs and technical characteristics of each athlete, thereby enhancing the relevance and effectiveness of their training [98]. Furthermore, the integration of artificial intelligence (AI) technology in the development of these training programs significantly advances the personalization of training [99]. AI technology possesses the capability to process vast amounts of data and extract valuable insights from it. When applied to the creation of training plans, AI enables the automatic generation of personalized training programs based on athletes' historical performance, physiological data, and training feedback. This intelligent training approach not only increases training efficiency but also provides a more scientific foundation for athletes' skill enhancement and injury prevention.

8. Conclusion

Single-leg stability training has proven to be an effective approach for preventing sports injuries, particularly among throwing athletes. This review offers insights into the underlying mechanisms that contribute to the potential benefits of single-leg stability training in reducing injuries in throwing sports. Furthermore, it suggests that future research should focus on enhancing our understanding of its mechanisms of action and developing more scientifically grounded and individualized training protocols to optimize its effectiveness in sports injury prevention.

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