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Article

Research on Dynamic Assessment of Proprioceptive Function Recovery and Optimization of Rehabilitation Training Programs After Sports Injuries

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Abstract: Sports injuries are common in athletic participation, and the recovery of proprioceptive function is crucial for restoring motor control, preventing re-injury, and enabling safe return to sport. This study focuses on the dynamic assessment of proprioceptive function recovery after different types of sports injuries and on the optimization of corresponding rehabilitation training programs. First, the research background, objectives, current domestic and international research status, and methodological framework are outlined, including assessment design, participant selection, and data analysis strategies. Second, the theoretical basis of proprioceptive function is introduced, covering its definition, physiological mechanisms, and the specific ways in which ligament, muscle, and joint injuries impair proprioceptive feedback and neuromuscular regulation. On this basis, a dynamic evaluation system and model for monitoring proprioceptive recovery over time are constructed, integrating quantitative tests, functional performance measures, and clinical scales. Furthermore, the basic principles, commonly used techniques, and program optimization strategies for proprioceptive-oriented rehabilitation training are analyzed, emphasizing progression, individualization, and task specificity. An empirical study is conducted through typical case analyses, in which different rehabilitation schemes are compared, and key factors influencing recovery efficiency are summarized. Finally, the main conclusions are presented, limitations of the current work are discussed, and directions for future research on assessment technology and training protocols are proposed, aiming to provide theoretical support and practical guidance for sports injury rehabilitation.

Keywords: proprioception; sports injuries; rehabilitation; functional assessment; motor control; training programs

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1. Introduction

Sports injuries are prevalent across various sports activities, affecting both professional athletes and fitness enthusiasts. These injuries can range in severity and often impact proprioception, which is a critical perception of the body's posture and movement state. Proprioception plays an essential role in maintaining normal motor function, and its impairment due to sports injuries can significantly influence recovery outcomes [1]. The degree of proprioception recovery is closely linked to the restoration of motor function and the likelihood of returning to sports. Consequently, the recovery of proprioception is central to sports injury rehabilitation. This study aims to improve the dynamic evaluation system for proprioception function recovery following diverse sports injuries, refine targeted rehabilitation training programs, and provide more scientific and effective guidance for rehabilitation practices. This has both theoretical and practical significance. Despite extensive research on proprioception recovery, current studies reveal gaps in systematic dynamic evaluation and the personalization and precision of rehabilitation training programs. This study will utilize a comprehensive literature review to synthesize relevant theories and findings. Through case analysis, it will explore the practical application of dynamic evaluation methods and rehabilitation training programs.

2. Theoretical Basis of Proprioception Function

2.1. The Concept and Physiological Mechanism of Proprioception

Proprioception is an individual's sense of the position, movement, and muscle tension of various parts of the body [1]. It enables accurate perception of the posture and movement of the body without relying on visual cues. For instance, when closing the eyes, one can accurately touch their nose, demonstrating the function of proprioception.

The physiological conduction pathway of proprioception is relatively complex, with information primarily collected by proprioceptors distributed throughout muscles, tendons, and joint capsules. These receptors include muscle spindles, tendon spindles, and joint receptors. Muscle spindles detect changes in muscle length and contraction speed, tendon spindles respond to changes in muscle tension, and joint receptors sense the position, direction, and amplitude of joint movement [2]. The receptors transmit the collected information to the spinal cord through afferent nerves, which then relay it to the somatosensory and motor areas of the cerebral cortex. After integration and processing by the brain, this information forms a perception of the body's state and regulates movement accordingly (As shown in Figure 1).

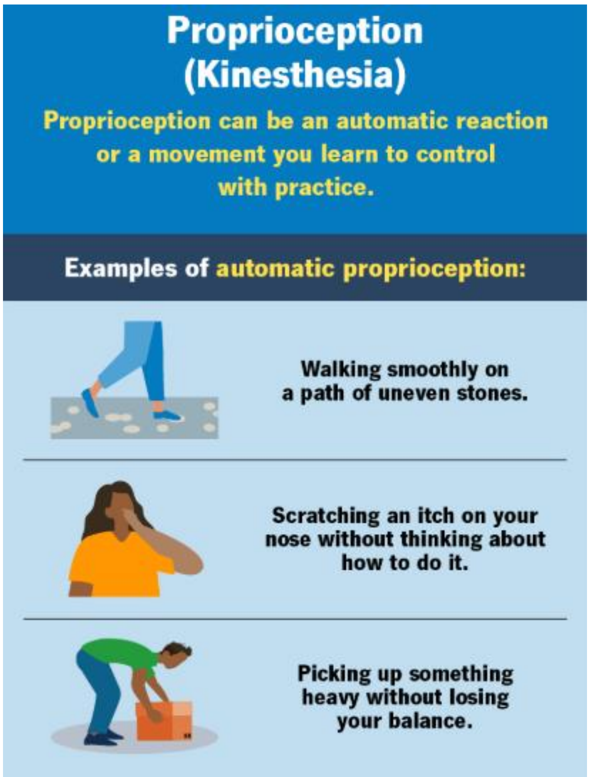

Figure 1. Examples based on proprioception.

Proprioception plays a crucial role in human movement. In maintaining body balance, it helps perceive changes in the body's center of gravity and facilitates timely adjustments through neural regulation, thereby preventing falls [3]. It ensures that muscle contractions and relaxations are coordinated, resulting in smooth and precise movements. When controlling movement, it continuously adjusts muscle activity according to movement goals to ensure that the accuracy and strength of the movement meet the required standards.

2.2. Effects of Sports Injuries on Proprioception

There are many common types of sports injuries, such as ligament injuries, muscle strains, and joint dislocations. Different types of sports injuries have distinct mechanisms of damage to proprioception. When a ligament is injured, the proprioceptors within the ligament are damaged, impairing their ability to perceive the position and movement of the joint, which disrupts the transmission of proprioception. Muscle strains can harm receptors, such as muscle spindles, reducing the muscle's capacity to sense changes in length and tension. Joint dislocations damage the tissues surrounding the joint, including the proprioceptors. Additionally, alterations in the normal anatomical structure of the joint can interfere with the proper transmission of proprioception.

When proprioception is impaired, athletes encounter various motor function challenges [3]. Joint instability is a common issue. Due to the inability to accurately perceive joint position and movement, joints are more likely to exceed their normal range of motion during physical activity, increasing the risk of reinjury.

3. Dynamic Evaluation of Proprioceptive Function Recovery After Different Sports Injuries

3.1. Evaluation Methodology

Traditional assessment methods are widely used in clinical practice [2]. The observation method involves making a preliminary judgment on proprioceptive function by directly observing the athlete's movements, postures, and sports performances, as observed by a rehabilitation therapist or doctor. For example, observing whether the athlete has an unstable gait when walking and whether they can maintain balance when standing on one leg. This method is simple and easy to implement, but it is subjective, and the evaluation results are not completely accurate.

The questionnaire survey involves designing a specialized questionnaire to allow athletes to self-evaluate their proprioception, including the perception of joint position and the sense of stability during exercise [3]. Using this method, the subjective feelings of athletes can be analyzed; however, it is significantly influenced by the athletes' own cognition and ability to express themselves, which may lead to biased results.

Clinical scale assessment has relatively standardized indicators. The Fugl-Meyer rating scale includes assessments of limb movement, balance, and sensation, with the sensation component involving the evaluation of proprioception [4]. The Berg balance scale requires subjects to complete a series of balance-related actions, such as standing up from a chair or turning around, and scores them based on their performance. These scales can provide relatively objective assessment data, but they also have certain limitations, such as incomplete assessment content.

Modern assessment technology offers a more accurate means of evaluating proprioceptive function. Neurological electrophysiology techniques, such as electromyography (EMG), can record the electrical activity of muscles, analyze the timing and intensity of muscle activity, and provide insights into muscle activation, indirectly reflecting the influence of proprioception on muscle control. Evoked potential (EP) techniques record the electrical responses of the central nervous system to stimulation, enabling the evaluation of proprioceptive nerve conduction pathways.

With the assistance of a motion capture system, the displacement, velocity, and acceleration of various parts of the athlete's body during exercise can be accurately recorded for sports function assessment. The force measurement platform can measure the ground reaction force of athletes during standing and walking, providing an analysis of their balance and movement control abilities [5]. These devices generate quantitative data for assessing proprioceptive function, making the evaluation results more scientific.

Biomechanical analysis applies the principles of biomechanics to evaluate an athlete's posture and movements [6]. For instance, by analyzing the forces exerted on an athlete when landing from a jump, it is possible to determine their ability to regulate movement through proprioception. These methods facilitate a deeper understanding of the role of proprioception in movement but require advanced equipment and specialized skills.

3.2. Dynamic Evaluation Model

Establishing a multi-dimensional evaluation index system is fundamental to constructing a dynamic evaluation model. This system should encompass joint position sense, movement sense, and balance ability. Joint position sense refers to an athlete's capacity to perceive the position of a joint. It can be assessed by having the athlete actively or passively move the joint to a specific position and then evaluating the accuracy of its placement [1]. Movement sense pertains to the perception of the direction and speed of joint movement. The athlete's ability to perceive these parameters can be tested by altering the characteristics of joint movement. Balance ability includes indicators such as static balance and dynamic balance, which measure the ability to maintain equilibrium on a moving platform.

The dynamic evaluation model, based on time series, utilizes evaluation data collected at different time points to plot a proprioceptive function recovery curve, illustrating its progression over time. Evaluations are conducted at various stages following sports injuries, specifically at 1 week, 2 weeks, 1 month, and 3 months post-injury. The results of each dimensional indicator from these evaluations are recorded and analyzed for patterns using statistical methods, which are then applied to develop the model.

4. Optimization of the Rehabilitation Training Program for Proprioception Function After Sports Injury

4.1. Basic Principles and Common Methods of Rehabilitation Training

Rehabilitation training must adhere to the principle of individualization, as each athlete has varying injury types, injury severity, distinct physical conditions, and specific sports-related needs. For example, for the same anterior cruciate ligament injury of the knee, the rehabilitation goals and training intensity will differ between young athletes and elderly athletes. Young athletes may be eager to return to the field, and training intensity can be relatively high. In contrast, elderly athletes may concentrate on regaining their daily living skills through moderate training intensity.

The principle of gradual progress requires that rehabilitation training should start from low intensity and gradually increase in intensity and difficulty. Taking the rehabilitation of ankle sprain as an example, simple ankle range of motion training can be performed in the early stage, such as slow flexion and extension movements; additionally, balance training can be gradually increased, such as standing on one foot on flat ground; in the later stage, complex movement training such as jumping and changing direction can be performed [7]. High-intensity training too early may lead to re-injury.

The principle of comprehensive rehabilitation emphasizes that rehabilitation training should cover multiple aspects [8]. Physical therapy, including the use of cold compresses, hot compresses, and electrotherapy, can help alleviate pain, reduce swelling, and create conditions for effective functional training. Functional training, including balance training and motor control training, directly promotes the recovery of proprioceptive function. Psychological rehabilitation should not be ignored. After sports injuries, athletes may experience anxiety, fear, and other emotions, which will affect the rehabilitation process. Therefore, psychological counseling will help athletes build confidence and actively cooperate with training.

There are many common rehabilitation training methods. In the context of balance training, the utilization of tools such as balance boards and balance balls has been demonstrated to be an effective method [9]. The subject is then instructed to stand on the balance board and adjust the body's center of gravity to maintain balance. The instability of the balance board should be gradually increased to increase the difficulty of the training. As an alternative approach, one may opt to assume a seated or standing posture on the balance ball, a maneuver that has been demonstrated to enhance the control of core and lower limb muscles.

Movement control training can enhance the ability to control joint movement through targeted joint activity exercises, such as slowly and accurately performing joint flexion, extension, and rotation. Additionally, strength training is also crucial. Resistance training can be used to enhance muscle strength and provide stable support for joints.

Perceptual training can be achieved through tactile stimulation, such as touching the skin with objects of varying textures, allowing athletes to perceive the difference. Additionally, temperature stimulation can be used, involving the application of alternating cold and hot towels around the injured area to enhance athletes' perceptual sensitivity.

In neurofeedback training, electromyographic biofeedback technology is widely used [3]. Electrodes are attached to the relevant muscles, and the electrical activity signals from the muscles are converted into visual or auditory signals through instruments and fed back to the athletes. Athletes adjust muscle activity according to the feedback signals, thereby improving the brain's ability to process and control muscle sensory signals.

4.2. Optimization Strategies for Rehabilitation Training Programs

Precision training based on assessment results is essential for optimizing rehabilitation training programs. By evaluating the recovery of proprioception function through a dynamic assessment model, adjustments can be made to the training content, intensity, and progression. For instance, if the assessment indicates slow recovery of the athlete's balance ability, the duration and difficulty of balance training can be increased. Conversely, if motor control ability is deemed satisfactory, the proportion of training in this area can be reduced, allowing for a greater focus on other aspects of rehabilitation.

Innovative training methods, combined with advanced technologies, can significantly enhance the effectiveness of rehabilitation training. Virtual reality (VR) technology enables the creation of simulated sports scenarios, allowing athletes to train in a virtual environment, such as simulating running and jumping, which can increase the enjoyment of training [8]. Additionally, VR equipment provides real-time feedback on athlete performance data, facilitating timely adjustments to training programs. Robot-assisted training offers further support by helping athletes perform specific movement exercises with robotic guidance, ensuring accuracy, particularly for individuals with limited motor ability during the early stages of recovery.

For example, a personalized rehabilitation training program was developed for an athlete recovering from an ankle ligament injury [10]. Initial evaluations revealed impaired ankle position sense and deficient balance ability. During the early phase of the program, the focus was on basic ankle range of motion and static balance exercises, including activities such as ankle flexion and extension, standing on one foot on a flat surface, and conducting 30-minute training sessions twice daily. After two weeks of evaluation, balance ability showed improvement, leading to the inclusion of balance board training and dynamic balance exercises, such as walking on a balance board, with sessions increased to three times a day for 40 minutes each. After one month of evaluation, significant improvements were observed across various indicators, and functional training, such as jumping and changing direction, was incorporated. This personalized program effectively restored the athlete's proprioception function and motor ability.

5. Empirical Research: Case Analysis of Different Sports Injuries

5.1. Typical Case Analysis

Case 1: Knee ligament injury: The patient, a 25-year-old basketball player, sustained an anterior cruciate ligament rupture (ACL) injury after abruptly stopping and changing direction during a basketball game [11]. The patient exhibited no concurrent chronic diseases and demonstrated robust overall health.

Dynamic assessment process: One week after the injury, the patient was administered a joint position sense test, in which they were asked to actively flex the knee joint to a specific angle while their eyes were closed [12]. The result of this test indicated a significant error. In the motion sense test, the knee joint was subjected to slow passive movement, and the patient had difficulty accurately judging the direction and speed of movement; the Berg Balance Scale score was low. Two weeks after the injury, the patient demonstrated a reduction in joint position sense error, an improvement in motion sense, and an increase in balance scale score. Subsequent evaluations at one month and three months post-injury demonstrated that all indicators persisted in their positive trajectory.

Rehabilitation training program formulation and implementation: In the early stage (1-2 weeks), passive knee range of motion training is performed to prevent joint adhesion; at the same time, isometric contraction training of the quadriceps is performed to enhance muscle strength; balance training is mainly static balance, such as standing on one leg. In the middle stage (3-6 weeks), active knee range of motion training is introduced, and resistance training is performed to enhance muscle strength. Balance training incorporates a balance board to increase the training difficulty. In the late stage (7-12 weeks), functional training is performed, including shuttle runs and jumps, to simulate movements in basketball.

Tracking and analysis of rehabilitation effects: Following a 12-week rehabilitation training regimen, the patient exhibited a return to normal knee joint position sense and movement sense, attained a normal Berg Balance Scale score, and demonstrated proficiency in executing fundamental basketball movements. He subsequently returned to the training facility for a brief training session.

Case 2: Ankle sprain. The patient was an 18-year-old football player who accidentally stepped on air while running with the ball during training, resulting in a sprain of the lateral ankle ligament [6]. The patient was previously healthy and had no history of ankle injury.

Dynamic assessment process: Three days after injury, the ankle position sense test was performed, and the patient had large errors in judging the position of ankle plantar flexion and dorsiflexion; in the motion sense evaluation, the patient demonstrated a lack of responsiveness to ankle joint movement. Additionally, the patient exhibited a reduced duration of single-leg standing. The evaluation process was conducted at one week, two weeks, and one month post-injury, with subsequent improvements observed in various indicators.

Rehabilitation training program formulation and implementation: In the early stage (1-7 days), physical therapy, such as the use of cold compresses and pressure bandages, is performed to reduce swelling and pain. At the same time, slight ankle mobility training is performed to prevent joint stiffness [13]. In the middle stage (2-4 weeks), strength training of muscles around the ankle joint is performed; balance training gradually transitions from standing on both feet to standing on one foot. In the later stage (5-8 weeks), stability training of the ankle joint is performed.

Tracking and analysis of rehabilitation effects: Following an eight-week period of recovery, the patient demonstrated a significant recovery in ankle proprioception function, allowing him to resume single-leg standing and other essential movements during football training without the risk of re-injury.

5.2. Case Studies and Experience Summary

The rehabilitation process of two typical sports injury cases is systematically analyzed, focusing on rehabilitation cycle, functional recovery trends, and training program adjustments to extract practical experience in proprioception rehabilitation for sports injuries. Comparing the rehabilitation effects of the two cases, it was observed that the rehabilitation period for patients with knee ligament injuries was longer, lasting 12 weeks. In contrast, the rehabilitation period for patients with ankle sprains was shorter, at 8 weeks. This difference is attributed to the relatively less complex structure of the knee joint and the less severe nature of the injury. Proprioceptive function is more challenging to restore in knee injuries. During the rehabilitation process, the balance ability and joint position sense recovery trends in both groups showed gradual improvement as rehabilitation training progressed. However, the motor sense of patients with knee injuries recovered at a slower pace.

From the perspective of adaptive adjustments in rehabilitation training programs, patients with knee ligament injuries initially focus on protecting the joints and promoting blood circulation, with functional training introduced gradually in later stages. In contrast, patients with ankle sprains can engage in mild range-of-motion training during the early stages [6]. This highlights the importance of flexibly adjusting training content and progress based on the location and severity of the injury when formulating rehabilitation training programs.

The case study provides significant insights into sports injury rehabilitation practices. Dynamic assessment is a critical component of the rehabilitation process, offering timely reflections on the patient's recovery and serving as a basis for program adjustments. Developing tailored rehabilitation training programs is essential for optimizing outcomes, with comprehensive consideration of individual patient variations being paramount [11]. Rehabilitation training should integrate multiple methods, account for the patient's psychological state, and enhance their motivation for recovery.

6. Conclusion

This study provides a comprehensive summary of dynamic assessment methods and strategies for optimizing rehabilitation training aimed at restoring proprioceptive function following various sports injuries. The dynamic assessment system encompasses both traditional and modern techniques. Establishing a multidimensional assessment index system and a dynamic model based on time series effectively captures the recovery trajectory of proprioceptive function. Rehabilitation training should adhere to principles of individualization, gradual progression, and comprehensive recovery. Common approaches include balance training and motor control techniques. Optimization strategies emphasize precision training informed by assessment outcomes, innovative methods integrating advanced technologies, and the development and execution of tailored rehabilitation plans.

This study acknowledges certain limitations. The sample size was relatively small, and the focus on two specific cases—knee ligament injury and ankle sprain—may not fully represent the entire spectrum of sports-related injuries. Additionally, the dynamic evaluation model employed in the research has inherent limitations, and the selection of evaluation indicators requires further refinement to enhance its applicability and accuracy.

Future research directions can focus on several key areas. In terms of proprioception assessment technology, there is a need to develop more accurate and user-friendly equipment and methods to enhance assessment efficiency and precision. Regarding rehabilitation training methods, exploring approaches that integrate emerging technologies, such as artificial intelligence-assisted rehabilitation, holds significant potential. Furthermore, interdisciplinary research should be strengthened by incorporating insights from fields such as neuroscience to deepen understanding of the mechanisms underlying proprioceptive function recovery. This would provide a more robust theoretical foundation for advancing sports injury rehabilitation practices.

References

1. S. Samal, S. Samal, and V. M. Thakre, "The Significance of Proprioceptive Training in the Post-Operative Rehabilitation of Patients Undergoing Achilles Tendon Reconstruction," *Cureus*, vol. 16, no. 2, 2024.
2. M. Stanković, I. Čaprić, B. Katanić, O. Špirtović, D. Maljanović, H. Nailović, et al., "Proprioceptive training methods (PTM) in female soccer players–a systematic review," *BMC Sports Science, Medicine and Rehabilitation*, vol. 16, no. 1, p. 101, 2024.
3. Neuropsychological, C. Free Communications, Thematic Poster: Concussion Assessment.
4. J. Ma, X. Liu, H. Lu, D. Zhang, T. Zhao, J. Wang, and S. Jin, "Effects of proprioceptive training in the recovery of patients submitted to meniscus surgery: systematic review and meta-analysis," *BMJ Open*, vol. 12, no. 6, p. e055810, 2022.
5. C. Hamlet, L. Fauci, J. R. Morgan, and E. D. Tytell, "Proprioceptive feedback amplification restores effective locomotion in a neuromechanical model of lampreys with spinal injuries," *Proceedings of the National Academy of Sciences*, vol. 120, no. 11, p. e2213302120, 2023.
6. O. Yılmaz, Y. Soylu, N. Erkmen, T. Kaplan, and L. Batalik, "Effects of proprioceptive training on sports performance: a systematic review," *BMC Sports Science, Medicine and Rehabilitation*, vol. 16, no. 1, p. 149, 2024.
7. D. Akseki, M. Erduran, and D. Kaya, "Sports injuries and proprioception: current trends and new horizons," in *Sports Injuries: Prevention, Diagnosis, Treatment and Rehabilitation*, Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 67–71.
8. S. M. Lephart and F. H. Fu, "The role of proprioception in the treatment of sports injuries," *Sports Exerc Inj*, vol. 1, no. 2, pp. 96–102, 1995.
9. E. Ergen and B. Ulkar, "Proprioception and ankle injuries in soccer," *Clinics in Sports Medicine*, vol. 27, no. 1, pp. 195–217, 2008.
10. J. Jerosch and M. Prymka, "Proprioception and joint stability," *Knee Surgery, Sports Traumatology, Arthroscopy*, vol. 4, no. 3, pp. 171–179, 1996.
11. J. Han, J. Anson, G. Waddington, R. Adams, and Y. Liu, "The role of ankle proprioception for balance control in relation to sports performance and injury," *BioMed Research International*, vol. 2015, no. 1, p. 842804, 2015.
12. S. M. Lephart, D. M. Pincivero, J. L. Giraido, and F. H. Fu, "The role of proprioception in the management and rehabilitation of athletic injuries," *The American Journal of Sports Medicine*, vol. 25, no. 1, pp. 130–137, 1997.
13. D. Kaya, B. Yosmaoglu, and M. N. Doral, Eds., *Proprioception in Orthopaedics, Sports Medicine and Rehabilitation*. Springer, 2018.