Journal of Studies and Researches of Sport Education

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The effect of eight weeks of rehabilitation program with combined exercises (aerobic, flexibility and resistance) on pain, balance and performance of athletics with a history of anterior cruciate ligament recovery 6 months after surgery

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Article information

Article history:
Received 04/01/2026
Accepted 11/04/2026
Available online 15, Sep ,2026

Keywords:

Training methods, competitive environment, motor and skill performance.

DOI:

https://doi.org/10.55998/jsrse.v36i5.1554

Journal of Studies and Researches of Sport Education
https://jsrse.edu.iq/index.php/home/index

Online ISSN: 2789-6560
Volume 36, Issue 5, 2026
Pages:31-52

Abstract

Purpose: The purpose of this study was to investigate the effect of eight weeks of rehabilitation program with combined exercises (aerobic, flexibility and resistance) on pain, balance, strength, anaerobic power and speed in track and field athletes with a history of anterior cruciate ligament surgery six months after surgery.

Method: This semi-experimental study was conducted with a pre-test and post-test design on 30 male track and field athletes (15 in each group). The participants were randomly divided into two groups of combined exercise and control. For eight weeks, three sessions per week, the training group performed a combined program including aerobic, flexibility and resistance exercises in a progressive manner. Variables of pain scale (VAS), balance (star test), strength (one repetition maximum squat), anaerobic power (rest test) and speed (10, 20 and 30 meters) were measured in the pre-test and post-test stages. Data analysis was done using the covariance test at a significance level of 0.05.

Results: The results showed that exercises The combination significantly reduced pain (P=0.001), improved balance (P=0.003), increased muscle strength (P=0.000), improved anaerobic power (P=0.000) and decreased the time of 10 meters (P=0.001) and 30 meters (P=0.000). But no significant change was observed in the speed of 20 meters (P=0.899).

Conclusion: An eight-week combined rehabilitation program can effectively improve most performance and pain indices in track and field athletes after anterior cruciate ligament surgery. This comprehensive approach can be used as a practical strategy for a safe return to competitive activities.

Due to the dynamic nature of the lower limbs, athletics is one of the sports that requires special training programs and the possibility of lower limb injuries is higher due to repeated pressure and explosive movements (Voskanian, 2013) (Xu et al., 2020). Athletes in various events (such as running, jumping, etc.) in this field are constantly under mechanical pressure. They are placed a lot, which can lead to chronic or acute injuries in the joints, ligaments, tendons and muscles of the lower limbs. One of the most common and serious injuries among track and field athletes and other sports that require a sudden turn and change of direction is the injury of the anterior cruciate ligament of the knee (Hasan et al., 2025)(Taha Yaseen, 2024) . This injury usually occurs when a person is making a sudden turn, landing improperly after a jump, or coming to a quick stop, which puts excessive stress on the ACL, causing it to stretch or tear (Hasan et al., 2025). This injury can also occur due to muscle imbalance, weakness in the hamstrings and quadriceps muscles, or improper movement techniques. Statistical studies show that this injury is more common in female athletes than in men due to anatomical and biomechanical differences (Hewett et al., 2006).

For example, in some studies, the prevalence of anterior cruciate ligament rupture among female athletes has been reported up to 8 times higher than that of males (Mandelbaum et al., 2005)(Saeed & Rahman, 2025) . These statistics emphasize the importance of paying attention to the prevention and proper rehabilitation of this injury. Athletes who suffer from anterior cruciate ligament rupture and undergo surgery are placed, after the initial improvement, they face many problems and challenges. These challenges go beyond just physical recovery and include psychological and social aspects as well (Wilson et al., 2021). Complications and challenges that athletes face after recovery and returning to professional sports include things such as loss of strength and muscle mass in the injured limb, reduced joint range of motion, chronic pain, and proprioceptive disorder (Bagley, 2015)(Albusac et al., 2024) . In addition, many athletes face psychological challenges such as depression, anxiety and uncertainty about their sports future, which can be a big obstacle in the way of returning to sports fields (Myer et al., 2012).

Pain is one of the most important issues that track and field athletes face after ACL surgery. This pain can be caused by the surgery itself, post-operative inflammation, or even nerve pain caused by tissue damage. To recover from this situation and successfully return to sports activities, there are various ways, including intensive physical therapy, light and gradual exercises, and in some cases, drug interventions (Canapp& CCRT). The purpose of these interventions, Restoring the full function of the knee joint, strengthening the surrounding muscles, improving balance and proprioception, and finally preparing the athlete for a safe return to sports. Sports exercises with a rehabilitation approach play a very important role in improving the condition after anterior cruciate ligament surgery and improving sports factors (Sun, 2024). A comprehensive rehabilitation program not only helps rebuild muscle strength and endurance, but also improves neuromuscular coordination, balance, and proprioception. These exercises should be done gradually and under the supervision of experts to prevent re-injury and the athlete to recover in the best possible way (Sun, 2024).

Strength, speed and power and balance are important performance factors in athletics, each of which plays an essential role in the success of athletes. Strength refers to the ability of muscles to exert force, speed refers to the ability to move quickly and cover a distance in the shortest possible time, and power refers to a combination of strength and speed, which is important in explosive movements such as jumping and sprinting. With correct and regular exercise Rehabilitation can improve all three of these factors and help the athlete to return to his previous level of performance after injury or even improve it (Björnsson et al., 2015).

An approach of rehabilitation exercises that can bring recovery and at the same time have a positive effect on the lateral muscles of the anterior cruciate ligament to improve functional factors and pain is the use of combined exercises (Sun, 2024). This approach is based on the idea that the improvement of only one factor is not enough for a full return to sports and all functional aspects as well as pain management should be comprehensively addressed. The purpose of these exercises is to create an optimal environment for rebuilding damaged tissues, strengthening the neuromuscular system and reducing pain (Wilson et al., 2021).

Combined exercises in this research include three main categories: aerobic, flexibility and resistance exercises. These exercises are necessary to strengthen the quadriceps, hamstrings and leg muscles, which play a vital role in knee stability and support of the anterior cruciate ligament (Bagley, 2015), (Björnsson et al., 2015). Combining these three types of exercises in a comprehensive rehabilitation program can simultaneously improve performance, reduce pain and increase the fitness of the athlete. Influence to return to sports (Wilson et al., 2021).

Despite significant advances in surgical techniques and rehabilitation protocols for anterior cruciate ligament tears, challenges remain in returning athletes to full performance and pain relief. Many past studies have focused on specific aspects of rehabilitation, such as single-joint resistance training, balance training, or aerobic training in isolation. Meanwhile, the complex and multifaceted nature of anterior cruciate ligament injury and the functional needs of athletes suggest the need for a more comprehensive approach. Therefore, the purpose of this study was to investigate the effect of eight weeks of rehabilitation program with combined exercises (aerobic, flexibility and resistance) on pain, balance and performance of athletics athletes with a history of anterior cruciate ligament recovery 6 months after surgery.

Methodology

The current research was a semi-experimental study with a pre-test and post-test design with a control group. The statistical population of this research includes male athletes from Babolsar city who underwent knee anterior cruciate ligament reconstruction surgery in the last six months. To select samples, first through a public call in Athletics clubs, athletics related athletics board in Babolsar city, eligible athletes were invited to participate. Male track and field athletes who had a history of anterior cruciate ligament rupture and reconstruction surgery in the past six months were eligible to enter the study. They should not have other concomitant knee or lower extremity injuries (such as severe meniscal tears, extensive cartilage damage, or collateral ligament tears) that would affect the rehabilitation process. Also, the history of systemic, neuromuscular, cardiovascular or respiratory diseases that prevent sports activity was rejected by confirming the health questionnaire and medical examination. The participants had refrained from taking drugs, supplements or stimulants for at least three months prior to the study and had not participated in non-standard rehabilitation programs or non-standard intense exercises in the one month leading up to the start of the study. Also, a passing score was obtained in basic performance tests (such as jumping and balance) to confirm the minimum necessary preparation, and their informed and written consent to participate and commitment to comply with training protocols and regular attendance at meetings was recorded.

in contrast, Individuals who refused to cooperate at any stage, had more than 15% absence (equivalent to two sessions in an eight-week period), acquired a new injury or had a recurrence of a previous injury, did not perform the exercise protocols correctly, or took any medication or supplement during the study that could affect the research variables, were excluded from the study. After the initial screening, eligible samples were selected as available and for matching, they completed the consent form, personal information and general health questionnaire, and physical activity questionnaire (to measure the level of activity before the injury). The sample size was determined with G*Power software, with a test power of 0.80, a significance level of 0.05, and an average effect size (0.25 for covariance analysis). Considering the interventional nature of the research and to increase the statistical power, at least 15 people in each group and a total of 30 people (two intervention and control groups) were considered. After selecting the eligible participants, they were divided into two groups of combined exercise and control in a simple random manner using the lottery method. The intervention group was designed and the control group followed the same routine The activity was allowed to carry out the standard physiotherapy program.

After completing the personal information and general health questionnaires as well as the informed consent form, the participants participated in a full briefing session. In this meeting, the exact objectives of the research, the implementation steps, the obligations of the participants and all the ethical points related to maintaining the confidentiality of information and the right to withdraw from the cooperation were clearly explained. After this meeting and ensuring the full understanding of the participants, the pre-test phase begins. At this stage, first, the level of pain of the athletes was measured using the Visual Analogue Pain Scale (VAS) (Begum& Hossain, 2019). This assessment was done both at rest and during normal daily activities, with the aim of determining the baseline level of pain before starting the rehabilitation program. In the following, the sports performance of the participants was evaluated by focusing on the three key factors of strength, speed and power. It was done to measure muscle strength using the squat test (Bazyler et al., 2015). In the speed section, the time required to perform a sprint of 10, 20 and 30 meters was evaluated (Pyne et al., 2008). Anaerobic capacity was also assessed with the Rest test (Abbasian et al., 2012) and balance with the Star test. (Gribble et al., 2012). Finally, after applying the intervention for eight weeks, the evaluations of the post-test stage were done again.

Training protocol (8 weeks)

The eight-week training program was divided into four two-week phases, and in each phase, the intensity, volume and complexity of the exercises increased gradually. Each exercise session began with a warm-up period consisting of 5–7 minutes of light aerobic activity such as slow walking on a treadmill at an intensity of 50–60% of maximum heart rate. After that, 5 to 8 minutes of dynamic stretching exercises such as rotating the main joints (knee, hip, ankle), swinging the legs forward, backward and sideways, and gentle stretching of the main muscles of the lower limb were performed. At the end of each session, a cool-down period including 5-7 minutes of light aerobic activities (40-50% of maximum heart rate) and 3-5 minutes of gentle static stretching for the main muscles involved (each stretch 20-30 seconds) was included.

Week 1-2: Initial phase (focusing on movement control and recovery)

During these first two weeks, exercises focused on regaining motor control and reducing initial pain. In the resistance section, athletes do 2 to 3 sets and 12 to 15 repetitions of movements such as squats with body weight (near the wall), lifting They performed supine leg extension, leg extension (standing or sitting), sitting knee extension (with limited pain-free range of motion), and standing hamstring flexion. The intensity of these exercises is about 50-60% of the highest repetitions and 60-90 seconds rest was given between sets. Balance exercises consisted of 2 to 3 sets of single leg balance (with support) for 30 to 60 s and, if tolerated, balance on unstable surfaces (e.g. balance hemisphere) was added. The aerobic part consisted of 10 to 12 minutes of treadmill (walking) with an intensity of 60-70% of the maximum heart rate (Bagley, 2015). Finally, flexibility exercises include 2 to 3 repetitions of static stretches for the hamstrings, quadriceps, hip flexors, and calves, each stretch being held for 20-30 seconds (17).

Week 3-4: Intermediate phase (increasing strength and endurance)

In this phase, the intensity and variety of exercises increased to improve muscle strength and endurance. In the resistance section, 3 sets and 10 to 12 repetitions of movements such as squats with body weight or light dumbbells (by holding the dumbbells in front of the chest), reverse lunges (step back) for each leg, leg presses with the machine, bending and straightening the knees with the machine (with resistance medium), and raising the pelvis in the supine position (hip thrust) was performed. The intensity of the exercises is about 60-70% of the most repetitions, and the rest between sets was 60-90 seconds. Balance and light jumping exercises consisted of 3 sets and 10 to 15 repetitions of short, controlled in-place jumps and light lateral jumps, which were performed with a focus on control and accuracy in landing. The aerobic part consists of 12-15 minutes of stationary bike or treadmill (slow running) at an intensity of 70-75% of the maximum heart rate and with a gradual increase in resistance/speed. In the flexibility section, the continuation of static stretches and adding slow dynamic stretches (3 to 4 repetitions, each stretch 20-30 seconds) was on the agenda (17).

Week 5-6: advanced phase (increasing strength and preparation for sports)

This phase focused on increasing muscle strength and preparing the athlete to return to more specialized sports movements. In the resistance section, 3 to 4 sets and 8 to 10 repetitions of movements such as weighted squats (with moderate weight), Romanian deadlifts, leg presses, lunges (step forward), stair climbing, and kettlebell exercises (such as light kettlebell swings) were performed. The intensity of the exercises increased to 70–80% of the highest repetitions and the rest between sets was 90–120 seconds. Strength and speed training consists of 3 sets and 8–10 repetitions of light vertical jumps, low–height box jumps (focusing on height and controlled landing). Also, 3 to 4 sets and 2 to 3 repetitions of short sprints (10–20 m) at moderate intensity and light agility training (such as sprinting with a focus on rapid change of direction) were also added. The aerobic part consisted of 15–20 minutes of running at a moderate speed on a treadmill, stationary bike or elliptical with an intensity of 75–80% of the maximum heart rate. Finally, flexibility exercises included more advanced static and dynamic stretches, focusing on full range of motion (3 to 4 repetitions, 30 seconds each stretch) (Solbakken, 2023).

Week 7–8: return to sports phase (increasing specialization and final preparation)

This final phase was designed with the aim of maximizing the athlete's preparation for a safe and effective return to sports competitions. In the resistance section, the intensity or volume of the exercises increased from the previous phase, so that 3 to 4 sets and 6 to 8 repetitions were performed with an intensity of 80–85%, and the rest between sets was increased to 2–3 minutes. Free weight and multi–joint exercises (such as light double lifts) were also included. Strength training and specialized speed includes 3 sets and 6 to 8 repetitions of explosive jumps (vertical and horizontal), 3 to 4 sets and 2 to 3 repetitions of 30–meter sprints with maximum intensity, and agility exercises specific to athletics, such as quick changes of direction and zigzag running. Also, running start simulation was done focusing on technique and explosive power. In the jumping section, vertical and horizontal jumps with increasing height/distance (3 sets and 6 to 8 repetitions) and depth jumps (from a low height) are added if tolerated (3 sets and 5 to 7 repetitions with controlled landing). The aerobic part consists of 20–25 minutes of high–speed or interval running on a treadmill with an intensity of 80–85% of the maximum heart rate or high-intensity interval training. Finally, flexibility exercises included advanced dynamic and static stretching and using a foam roller to improve muscle recovery (3 to 5 repetitions, each stretch lasting 30 seconds or more) (Solbakken, 2023).

speed

To measure sprinting, each participant participated in 10, 20, and 30 m sprint tests after a proper warm-up. Each distance was repeated twice and between each test, the participants rested for three minutes (Pyne et al., 2008).

anaerobic power

From the anaerobic test Rust was used to measure anaerobic power. The method of execution of the test is that a distance of 35 meters is considered first. After the initial warm-up, they covered a distance of 35 meters for six times, with a 10-second rest between each time. After recording the records in seconds; By putting in the following formula, the maximum anaerobic power was calculated (Abbasian et al., 2012).

3 time (seconds) ÷ 2 distance (meters) × body weight (kilograms) = power (watts)

6 ÷ the sum of all six stages of running = average power (watts)

Strength test

The process of strength test with squat (one repetition maximum) In this research, lower body strength was measured using the squat test of one repetition maximum. This method determines the maximum weight a person can lift for one full repetition with correct technique. The test process included the following steps. Before starting the main test, the participants were familiarized with the correct squat technique. This familiarization included teaching the correct movement form, proper squat depth (at least up to 90 degrees knee joint bending) and safety tips. After that, a general warm-up consisting of light aerobic activity such as stationary cycling or treadmill (5 to 10minutes) and dynamic stretching exercises were performed. Then, a dedicated warm-up using an empty barbell (5-10 repetitions) and then gradually increased with lighter weights. The purpose of this stage was to prepare the muscles and joints to bear heavier weights and prevent injuries. After a proper warm-up, the participants began to perform the squat test with increased weights. The process was such that in the first set, the participant started with a weight that they could do 5 to 10 repetitions. In the second set, the weight was increased so that the participant could perform 3 to 5 repetitions. In subsequent sets, the weight was gradually increased and the number of repetitions decreased (e.g., 2-3 repetitions), until the individual reached a weight that could be used to complete one complete repetition. Between each set, sufficient rest (3 to 5 minutes) was provided for complete recovery. The maximum weight that the participant could lift for only one complete repetition and following the correct squat technique was recorded as the maximum repetition strength. Attempts to determine 1RM should not exceed 3 to 5 sets to avoid excessive fatigue of the participant (Urquhart et al., 2015).

Measure the amount Pain sensation visual analog scale

A visual analog scale (VAS) was used to evaluate the degree of pain sensation after the delayed stimulator activity. This scale, developed in 1983 by Price et al., is a simple yet effective tool for measuring subjective pain intensity. The VAS scale was a 10 cm long horizontal line marked with "0" or "no pain" at one end and "10" or "worst imaginable pain" at the other end. Participants were asked to mark the point on this line that best represented their current pain intensity. The distance from the "no pain" point to the point marked by the individual was recorded as the pain score (Begum& Hossain, 2019).

Star balance test

A field evaluation tool is dynamic balance in which the person stands with one foot in the center of a star or shape (Y) and with the other foot in different directions of drawn lines (usually 8 directions or 3 directions in the modified version) to reach the maximum possible distance (Kim et al., 2022).

Data analysis method

In this research, to analyze the data, descriptive statistics will be used first to calculate the average and standard deviation of the data in the form of a table and Forms should be provided. Shapiro-Wilk test was used to check the normality of data distribution. Also, to check the homogeneity of variances, Lon's test (defaults of covariance analysis test) was used. Covariance test was used to check the differences between groups and within groups. If the results of this test are significant, Bonferroni's post hoc test was used to determine pairwise differences between groups. The level of statistical significance in this research was $p<0.05$. All statistical operations were performed using SPSS version 25 statistical software.

Results

Descriptive information including age, height, weight and body mass index of the subjects by group in Table 1. is provided. One-way analysis of variance test was used to determine the homogeneity of the groups. Based on the results, there was no significant difference between the individual characteristics of the subjects distributed in the groups, and in other words, the randomized groups were homogeneous ($P<0.05$).

Table 1. Mean ± standard deviation of the demographic characteristics of the subjects in the respective groups

شاخص توده بدنی (کیلوگرم/مترمربع)	وزن (کیلوگرم)	قد (سانتی‌متر)	سن (سال)	گروه
23/2±91/13	73/6±06/09	175/7±00/96	25/6±33/10	تمرین
24/2±62/18	170/6±20/86	170/6±20/86	24/4±66/16	کنترل

The results of covariance analysis for the pain scale showed (=0.53).Figure (1), balance (P = 0.61, F1.27, η2, 0.27), balance (P = 0.54, P = 0.2,003, F1.61, 27) Figure (2), muscle strength (P = 0.56, P = 0.2,000, F1.27 = 35.51), Figure (3), anaerobic power (P = 0.70, P = 0.2,000 Figure (4), speed of 10 meters (P = 0.27, η2,002, 0.63) Figure (4), speed of 10 meters (P = 0.27, η2,002) Figure (5-a), speed of 30 meters ($P = 0.48$, $\eta2,000, 0.27$) Figure (5-b) there is a significant difference between the two control and training groups. On the other hand, in the speed of 20 meters ($P = 0.89$, $\eta2 = 0.01$, $F1 = 0.01, 27$) Figure (5-b) No difference was observed between the two groups.

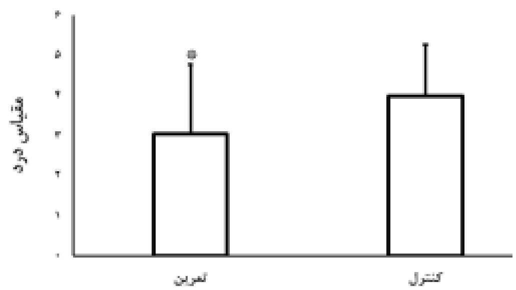

Figure 1. Status of the groups with the adjusted mean of the analysis of covariance test for pain

*: significant difference with the control group

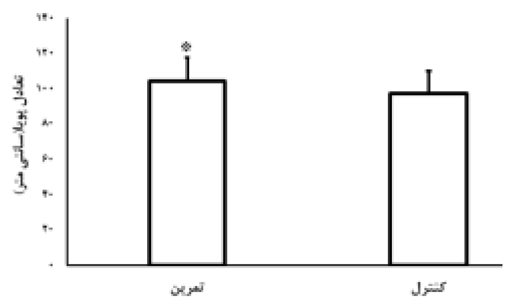

Figure 2. The status of the groups with the adjusted mean of the analysis of covariance test for balance

*: significant difference with the control group

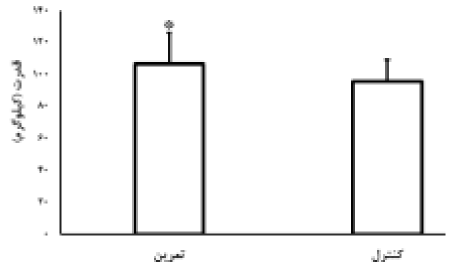

Figure 3. Status of the groups with the adjusted mean of the analysis of covariance test for power

*: significant difference with the control group

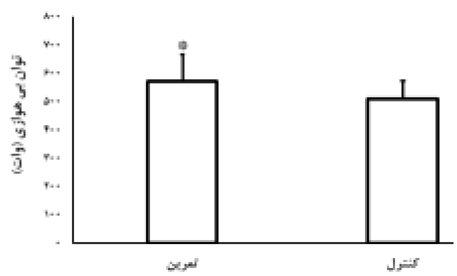

Figure 4. The status of the groups with the adjusted mean of the analysis of covariance test for anaerobic power

*: significant difference with the control group

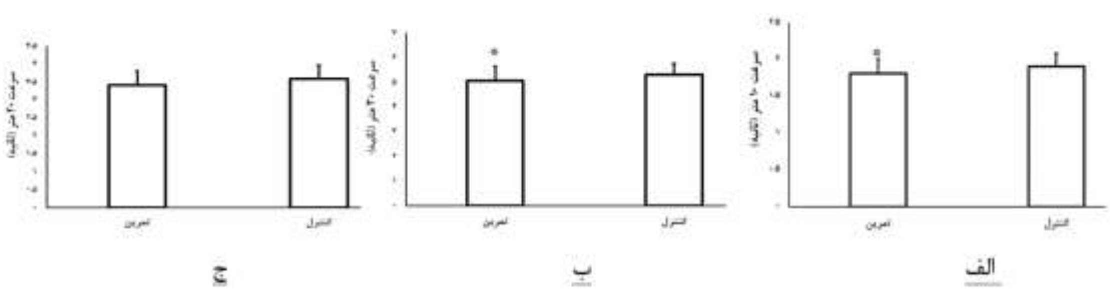

Figure 5. The status of the groups with the average adjusted from the covariance analysis test for 10m speed (a), 30m speed (b) and 20m speed (c)

*:Significant difference with the control group

discussion

This study was conducted with the aim of evaluating the effects of an eight-week period of combined exercises (aerobic, flexibility and resistance) on pain, balance, strength, anaerobic power and speed indicators in track and field athletes six months after their anterior cruciate ligament surgery. The results of this research showed a significant reduction in pain in the exercise group.

This finding is consistent with the observations of (Wilk et al., 2003) and (Nyland et al., 2023), who emphasized the necessity of multifaceted programs in ACL injury management. Book Thorpe and colleagues also pointed out the benefits of various methods in reducing symptoms after reconstruction (Buckthorpem 2019).

The pain reduction mechanism in this program is multifactorial. Regular exercises activate descending inhibitory pathways in the central nervous system that block the transmission of painful signals in the spinal cord (Sitges et al., 2021). At the same time, reducing pro-inflammatory cytokines and improving local blood circulation are also involved in this process (Sullivan et al., 2012). Strengthening weak muscles and correcting incorrect movement patterns help to reduce pressure on damaged structures (Sullivan et al., 2012). In addition, the release of endorphins during physical activity It creates a natural habitat (Booth et al., 2017).

Some researchers have provided different results. (Mahmoudi et al., 2022) showed that the response to different types of exercise is not the same in different populations. (Yovasirassi et al., 2013) reported that the duration of the intervention plays a decisive role in achieving desired results (Uusi et al., 2017). (Lee et al., 2023) pointed out the impact of the measurement method on the findings (Lee et al., 2023). These differences are likely due to variations in exercise protocols, sample characteristics, measurement tools, and program adherence. Foley et al. showed that adherence to exercise is one of the key success factors (Foley et al., 2011).

Other findings of the present study showed a significant improvement in balance in the intervention group. This result with Meyer et al.'s research (Myer et al., 2008). which confirmed the effectiveness of neuromuscular techniques in eliminating functional defects, is consistent (Myer et al., 2008). Adams and colleagues also introduced criterion-based rehabilitation as an effective strategy (Adams et al., 2012). (Etizen et al., 2010). They showed that the progressive program can be efficient even in the first stages after the injury (Sitges et al., 2021).

Balance improvement occurs through several pathways. Retraining movement patterns and strengthening neuromuscular control increases coordination between sensory-motor systems (Myer et al., 2008). Progressive exercises allow the nervous system to adapt to new functional demands and improve joint stability (Eitzen et al., 2010). (Clague et al., 2015) showed that improving dynamic balance is directly related to success in returning to sports (Clagg et al., 2015). In their meta-analysis, (Su et al., 2025) (34) mentioned the preventive role of balance exercises in reducing the incidence of ACL injuries (Su et al., 2025). Hassan et al emphasized the importance of comprehensive assessment of balance in track and field runners (Hasan et al., 2025).

However, some studies have reported inconsistent findings. (Zolt et al., 2017) observed that ACL damage only affects dynamic balance and voluntary quadriceps activation and does not affect other neuromuscular aspects of the healthy leg (Zult et al., 2017). (Boyle et al., 2016) reported different patterns of improvement in adolescents compared to adults, which is probably related to developmental differences (Boyle et al., 2016). (Clark et al., 2014) showed that the analysis method can affect the reported results (Clark et al., 2014). These differences may be due to differences in the age of the participants. Assessment methodology, timing of intervention and complexity of damage.

Also, the results of the present study showed a significant increase in anaerobic power and a decrease in sprint time at distances of ten and thirty meters, but no significant change was observed at a distance of twenty meters. (Sukman et al., 2018) reported that speed interval training improves anaerobic power and performance (Sukman et al., 2018). (Suisi et al., 2011) also confirmed the effectiveness of the combined program in the period of four to six months after surgery (Suisi et al., 2011).

The improvement of anaerobic power occurs through the increase of muscle phosphocreatine reserves and the activity of glycolytic enzymes (Glaister et al., 2006). Resistance and explosive exercises cause the activation of type IIx fibers, which directly affect the production of explosive force. (Glaister et al., 2006). showed that anaerobic power can indirectly affect multi-repetition speed performance (Glaister et al., 2006). Gardner argued that compound exercises increase motor performance through neural training and muscle co-activation (Gardiner, 2016). By improving oxidative capacity, aerobic exercise promotes faster recovery between burst repetitions and leads to sustained speed over longer intervals. They become (Glaister et al., 2006).

Several studies have presented different results. Olivier et al showed that the one-legged training program does not have a significant effect on speed or anaerobic power, which is probably due to the lack of similarity to real movements (Olivier et al., 2010). (Lim et al., 2022) reported that despite the improvement in strength, there was no significant improvement in intermediate distances, which they attributed to residual neuromotor limitations (Lim et al., 2022). Murray showed that speed interval training is more effective on shorter or longer distances than intermediate distances (Murray, 2022).

The lack of effect on the twenty-meter distance is probably because this distance requires a careful balance between initial acceleration and maintaining speed. If the training program does not affect both aspects equally, the improvement in this distance will be more limited. This distance may also be affected by biomechanical factors such as step length and frequency, which are not specifically targeted in the current program.

Muscle strength

The findings showed a significant improvement in muscle strength. This result is consistent with the observations of (Gukler et al., who found structured resistance training to be effective in the middle stages of rehabilitation (Golberg et al., 2024). (Welling et al.,

2019) They reported that the progressive resistance program leads to full recovery of strength (Welling et al., 2019). Stoyanov ich and colleagues emphasized the effectiveness of eccentric exercises in the final stages of rehabilitation (Stojanović et al., 2023).

Strength improvement occurs through the induction of muscle hypertrophy and the increase of type II fibers (Holm et al., 2006). At the same time, improving neuromuscular coordination and reducing neural suppression play a key role (Palmieri-Smith et al., 2008). (Palmieri-Smith et al., 2008) showed that the decrease in quadriceps strength is mainly due to neural suppression, which resistance training can remove (Palmieri-Smith et al., 2008). Aerobic exercises play an indirect role by facilitating recovery after resistance exercises (Buckthorpe et al., 2024).

Some studies have reported more limited results. In their systematic review, Petersen et al. (Petersen et al., 2014) showed that many athletes still have a lack of strength even after completing standard programs (Petersen et al., 2014). (Moisala et al., 2007) reported that some patients have strength asymmetry even two years after surgery (Moisala et al., 2007). (Casamara et al., 2021) emphasized that the number and frequency of supervised sessions have a decisive effect on the final results (Czamara et al., 2021). These differences are likely related to program design, intervention timing, Graft type and individual characteristics are related (Cavanaugh& Powers, 2017).

This research had limitations. The statistical sample was exclusive to male track and field athletes, which limits generalizability. The duration of the intervention was eight weeks and there was no long-term follow-up. Using clinical tests instead of more advanced methods is also considered a limitation. For future research, it is suggested to conduct long-term follow-up studies to evaluate the sustainability of improvements. It is recommended to investigate this program in more diverse populations, including women, athletes of different disciplines, and people with various types of grafts. The use of advanced evaluation methods such as electromyography and 3D biomechanical analysis can provide a better understanding of the mechanisms. Designing more specialized exercises to improve speed in middle distances is also necessary. From a practical perspective, the results suggest that rehabilitation professionals use progressive and personalized combination programs.

conclusion

The findings of this research showed that an eight-week combined rehabilitation program can effectively reduce pain, improve balance, strength and anaerobic power, and increase speed in intervals. Promote short and long. These results are consistent with most of the available evidence and confirm certain physiological mechanisms. Despite limitations such as lack of effect on intermediate distance, limited sample, and lack of long-term follow-up, this study highlights the importance of comprehensive approaches in rehabilitation after ACL surgery. Future programs should be designed according to the specific needs of each sport and athlete to facilitate a safe return to competitive activities.

Resources

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