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A Randomized Controlled Trial Comparing the Physical Performance of Soccer Players With and Without Anterior Cruciate Ligament Reconstruction While Undergoing Knee Injury Prevention Training

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ABSTRACT

Background: Anterior cruciate ligament (ACL) rupture is one of the most severe and complex knee injuries commonly occurring in soccer. The Sportsmetrics Soccer Training (SMST) protocol is a well-established program for preventing knee injuries and enhancing soccer players' performance. This study aimed to compare the effect of the SMST injury prevention protocol on the performance of soccer players with and without anterior cruciate ligament reconstruction (ACLR).
Methods: This research employed a semi-experimental design, including 42 soccer players aged 18–30, each with at least three years of regular soccer experience. Participants were divided into two groups of 21 subjects: players with ACLR and those without ACLR. Physical performance was evaluated using the Illinois Agility Test, 40-Yard Sprint Test, and Sargent Vertical Jump Test in both groups before and after six weeks of intervention. The SMST protocol was conducted in three 90-minute weekly sessions for six weeks. Statistical analyses were performed to assess intra-group differences using the dependent t-test and inter-group differences using the covariance analysis test ($P \le 0.05$).
Results: The dependent t-test results demonstrated significant improvements in speed (P=0.01), agility (P=0.01), and explosive power (P=0.01) in both groups following six weeks of SMST training. However, the results of the covariance analysis revealed no significant differences between the two groups in terms of speed (P=0.57), agility (P=0.07), and explosive power (P=0.71) after six weeks of training.
Conclusion: The improvements in performance indicators among the participants were primarily attributed to the alignment between the components of the SMST protocol and the performance evaluation tests. SMST training is highly recommended for healthy and ACLR soccer players, as it effectively enhances physical and athletic performance while reducing the risk of ACL injury and re-injury.

Introduction

Research on soccer has shown that 72% of injuries occur in the lower extremities, with soft tissue injuries accounting for 4–43% of these cases, including acute and chronic strains. Among these, injuries to the lower limb, particularly the knee and ankle joints, are the most common [1]. ACL rupture is considered the most critical injury in soccer [2], frequently occurring during activities such as jumping, running, landing, cutting movements, acceleration, and deceleration [3].

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Soccer matches require players to perform fast-paced actions such as running, dribbling with rapid changes in direction, kicking, and throwing. These movements must be executed quickly and with precision. Consequently, coaches and players must implement strategies that optimize movement execution and enhance the players' ability to increase and decrease speed efficiently. Achieving these goals necessitates a high level of physical fitness and athletic performance [4].

Soccer players must efficiently develop their physical abilities to meet the increasing demands of games and training throughout the season [5]. Jumping (power), sprinting (speed), cardiorespiratory endurance, and agility are the key components of physical fitness in soccer [6]. For professional players competing in high-stakes matches, speed contributes to 45% of their performance, while power accounts for 16% [7].

To assess power in athletes, the vertical jump test (Sargent) is widely regarded as the most reliable option [8]. Similarly, the 40-yard speed test is a popular tool for measuring soccer players' speed and evaluating their potential for selection in national teams [9]. Studies have consistently shown that professional soccer players outperform amateur players in these assessments [10].

Agility, a crucial component of performance in field sports like soccer, should be an integral part of training programs [11]. Agile athletes demonstrate superior endurance and stability during quick movements, which reduces the risk of sustaining injuries or re-aggravating pre-existing ones [12].

The prevention of injuries is a critical focus in professional soccer. Studying the effects of an injury prevention exercise program (IPEP) is essential for two main reasons: (a) enhancing performance reduces the risk of injuries, and (b) improved performance increases program adherence and the likelihood of success in real-world applications [13]. Injury prevention measures can be tailored based on the nature and location of the most common injuries in each sport [14].

Experts in injury prevention highly recommend implementing neuromuscular training programs for coaches and athletes as an effective method to prevent injuries, enhance performance techniques, and extend athletic careers [14]. Several neuromuscular exercise protocols have been developed, including FIFA 11, FIFA 11+, the Prevent Injury and Enhance Performance Program (PEP), and the Knee Injury Prevention Program (KIPP) [15]. Among these, SMST training, a novel neuromuscular protocol designed by injury prevention specialists, specifically targets reducing lower limb injuries and enhancing the physical performance of soccer athletes [16]. This protocol incorporates agility drills, resistance training, cardiovascular endurance activities, speed exercises, and plyometric training [16].

Previous research has utilized various SMST exercises to achieve preventive and performance-enhancing objectives [17]. The SMST protocol has demonstrated its ability to reduce ACL injuries and improve soccer players' performance, highlighting its effectiveness as a comprehensive approach [18]. However, despite the apparent benefits, soccer players often focus solely on activities that enhance performance and increase their chances of success, frequently overlooking injury prevention exercises due to the misconception that they do not directly contribute to performance improvements [2].

On the other hand, many coaches are reluctant to implement injury prevention programs because they focus on achieving team goals. Additionally, they often perceive the impact of such programs on enhancing athletes' physical abilities as insufficient. Therefore, it is essential to develop a holistic and effective protocol that can simultaneously prevent injuries and improve the physical fitness of soccer players.

Findings on SMST training indicate its positive impact on reducing lower extremity injuries. However, the physical effects of this training program on soccer players who have undergone ACL reconstruction surgery remain unexplored. Consequently, this study aimed to address this gap and investigate the matter.

Methods

This study employed a pre-test-post-test design in a semi-experimental format. The statistical population consisted of soccer players from the Premier League and the First and Second Divisions. These players had at least three years of team training experience in soccer and were aged between 18 and 30. This age range was selected to minimize the effects of initial training differences. Based on prior studies and calculations using G Power software, a minimum of 42 subjects was necessary to achieve a statistical power of 0.8, a reliability coefficient of 0.8, and a significance level of 0.05.

From this statistical population, 42 subjects were selected through purposive and accessible sampling. These individuals were randomly assigned to two groups: an experimental group (n=21, with ACL reconstruction) and a control group (n=21, without ACL reconstruction).

The inclusion criteria were as follows:

- 3–5 years of experience in teamwork and training at the club level in soccer.
- Subjects in the experimental group had undergone ACL reconstruction surgery.
- No history of diseases associated with impaired balance.
- A body mass index (BMI) within the normal range.
- No lower limb injuries, apart from ACL injuries, within the previous six months.
- Absence of apparent lower limb abnormalities (e.g., anteversion, genu valgum, genu varum, tibial torsion, flat feet), as assessed using the New York test.
- A time frame of no less than six months and no more than 24 months since ACL reconstruction.

Exclusion criteria included:

- Missing more than three sessions or two consecutive sessions of the SMST knee injury prevention program.
- Experiencing pain or discomfort during training.
- Suffering an injury during training.
- Voluntary withdrawal from the study [17].

The ethical considerations of this study included safeguarding participants' confidentiality, employing a skilled instructor and examiner to minimize harm, allowing participants to withdraw from the research at any time, and providing a clear explanation of the research purpose to all participants before initiating the exercises. Written informed consent was obtained from all participants.

This research received approval from the Ethics Committee of the Iranian Research Institute of Physical Education and Sport Sciences under the approval code IR.SSRC.REC.1402.093.

Data Collection

At the outset of the research process, the demographic characteristics of the athletes were documented and measured. Following a specialized warm-up, participants completed three performance tests: the Illinois Agility Test (ICC=0.9), the 40-yard Sprint Test (ICC=0.98), and the Vertical Jump Test (Sargent Jump) (ICC=0.99). Subsequently, both groups participated in the SMST program for 18 sessions. The training spanned six weeks, with three weekly sessions, each lasting approximately 90 minutes. After completing the 18 training sessions, both groups underwent a post-test, during which all evaluations were repeated under identical conditions to the pre-test.

Sportsmetrics Soccer Training

To optimize their performance, soccer players must fully understand the SMST protocol's foundational components. This protocol comprises four training elements: agility and reaction, speed and endurance, plyometrics, and strength. The training program is designed so that players perform a variety of exercises each week while remaining within the structure of the same training sections. The protocol is tailored to meet the specific requirements of each section.

Essential exercise tools include cones, training funnels, resistance therabands, ladders, and Pilates bands. The weekly training program was different for each week, and all instructions for the week's exercises were delivered at the start of each week. Both groups received theoretical guidance on the weekly program before commencing their practical sessions.

Each training session lasted between 60 and 90 minutes. The SMST protocol was implemented during the pre-competition season, overlapping with the bodybuilding phase of training. Both groups participated in the Sportsmetrics training as outlined in Table 1.

Illinois Agility Test

Agility was assessed using the Illinois Agility Test in the current study, which has demonstrated a reliability coefficient of 0.98 in previous research [19]. The test setup consisted of eight cones positioned at standard distances following the test's protocol.

Participants began the test in a prone position, facing downward with their heads towards the starting line and their hands placed next to their shoulders. At the sound of the command to start, the timer was activated. The athlete quickly rose to their feet and sprinted 10 meters to circle a cone before returning over the same distance. They then navigated a slalom

Table 1: Sportsmetrics soccer training program [17]

Week (Sessions)	Jump Training	Agility, Reaction	Acceleration, Aerobic, Endurance	Ladders-Quick Feet, Dot Jump Drills
Week 1 (1-3)	Wall jump (20 s); tuck jump (20 s); squat jump (10 s); barrier jumps (20 s each); side-to-side; forward backward; 180 jump (20 s); broad jump (5 repetitions); bounding in place (20 s)	Serpentine run ¼ field (3 repetitions); wheel drill: listen to the instructor, 30 s, 2 repetitions	Partner push-offs, hold 5 s, 5 repetitions (sprint to the 10-yd line and back); sprint-backpedal, ½ field or 50 yd, 5 repetitions; 4 laps around the field (1280 yd)	Ladder: up-up and back-back, 2 repetitions; dot drill: double leg jumps, 5 repetitions *3
Week 2 (4-6)	Same as sessions 1–3; add 5 s to each jump; add 5 repetitions to the broad jump	Modified shuttle ¼ field, 3 repetitions; sprint-stop feet listen, 30 s, 2 repetitions	Acceleration with a band (to 10-yd line); sprint with ground touches backpedal, ½ field or 50 yd, 5 repetitions; 100-yd shuttle: 3 * 100 (300 yd), 4 repetitions	Ladders: toe touches, 2 repetitions; dot drills: add split leg jumps, 5 repetitions * 3
Week 3 (7-9)	Wall jump (25 s); tuck jump (25 s); triple broad into vertical jump (5 repetitions); squat jump (15 s); barrier hops (25 s each); side-to-side; forward-backward; single-leg hop (5 repetitions); scissors jump (25 s); bounding for distance (1 run)	Square drill, 30′ * 30′ box, 2 repetitions; sprint quick feet-listen, 45 s, 2 repetitions	Partner push-offs, hold 10 s; 5 repetitions (sprint to the 10-yd line and back); ¼ eagle, instructor cued, into a sprint, jog back, ½ field or 50 yds, 6 repetitions; 50-yd shuttle: up and back 3 * 100 (300 yds), 4 repetitions	Ladders: outside foot in, 2 repetitions; dot drills: add 180 split leg jump, 5 repetitions * 3
Week 4 (10-12)	Same as sessions 7–9; add 5 s to each jump; add 3 repetitions to triple broad into vertical jump	Nebraska drill, 30' long, 4 repetitions; reaction drill-watch instructor point, 45 s, 2 repetitions	Acceleration with band (to 20-yd line); box drill, sprint-90-backpedal, ½ field, 3 repetitions; 50-yd cone drill: 10 y-back, 20 y-back, 30 y-back, 40 y-back, 50 y-back; 4 repetitions	Ladders: in-in, out-out, 2 repetitions; dot drills: add single-leg hops, 5 repetitions
Week 5 (13-15)	Wall jump (20 s); step, jump up, down, vertical (30 s); squat jump (25 s); mattress jumps (30 s each); side-to-side; forward-backward; triple single-leg hop, stick; (5 repetitions each leg) jump into bounding (3 runs)	Illinois drill, 15' * 10', 4 repetitions; reaction mirror drill pressing, 60 s, 2 repetitions	Partner push-offs, hold 15 s, 5 repetitions (sprint to the 10-yd line and back); sprint-180-backpedal, jog back, ½ field or 50 yds, 7 repetitions; jingle jangle 20 yd, up and back * 5 (200 yds), 5 repetitions	Ladder: up-up and backback, 2 repetitions; dot drills: combo all jumps, 5 repetitions * 3
Week 6 (16-18)	Same as sessions 13–15; add 5 repetitions to step, jump up, down, vertical; add 1 run to jump into bounding	T-drill: 5–10–5, 4 repetitions; advanced wheel drill: listen to the instructor, 60 s, 2 repetitio	Acceleration with a band (to 30-yd line); sprint-360-sprint (jog back), ½ field or 50 yd, 7 repetitions; jingle jangle 10 yd, up and back * 5 (100 yd), 6 repetitions	Ladder: 1 foot forward, 1 foot backward (scissors), 2 repetitions; dot drills: combo all jumps, 5 repetitions

Note: yd: yard

course consisting of four cones, finishing with a final 10-meter sprint past the finish line, where the timer was stopped.

Each participant performed the test three times, and their best recorded time was considered the final result.

40-yard Sprint Test

The participants' speed was measured using the 40-yard sprint test, which demonstrated a high level of reliability with an Intraclass Correlation Coefficient (ICC=0.97). Two cones were placed 40 yards (36.58 m) apart on the ground, marking the start and end lines. Participants were instructed to sprint at maximum speed, ensuring they passed the end cones without decelerating near the finish line. Two examiners were involved in the test—one positioned at the starting line and the other at the finish line. Each participant completed the test three times, and their best recorded time was considered as their final result [9].

Vertical Jump Test (Sargent Jump)

The Sargent Jump Test was employed to evaluate the explosive power of the lower limbs. The reliability of the Sargent Jump Test is reported to range between 0.90 and 0.99, with a validity of 0.78 [20]. To conduct the test, the athlete stood adjacent to a wall and extended one arm upward while keeping their feet flat on the ground. The fingertips of the extended arm were marked or recorded, representing the standing reach height.

The athlete then leaped vertically from the same position, using both arms and legs for propulsion, aiming to reach as high as possible. At the jump's apex, the athlete attempted to touch the wall. The score was calculated as the difference between the standing reach height and the height reached during the jump. Each participant performed the test three times, and their best result was recorded as the final score.

Statistical Method

Descriptive statistics were used to calculate the mean and standard deviation for height, weight, age, and body mass index (BMI). The Shapiro-Wilk test was employed to assess the normality of the data distribution. For intra-group comparisons, a dependent t-test was applied, while an analysis of covariance (ANCOVA) was used to compare results between the groups with and without ACLR. Statistical calculations were performed using SPSS version 27, with the significance level at P≤0.05.

Results

Table 2 presents the demographic characteristics of the subjects, including their mean and standard deviation.

For intra-group comparisons, a dependent t-test was employed. Table 3 displays the results for the ACLR group, while Table 4 presents the results for the non-ACLR group. The outcomes in Table 3 indicate a significant difference in the performance factors of speed (P=0.01), agility (P=0.01), and power (P=0.01) between the pre-test and post-test after six weeks of SMST training in the ACLR group. These findings demonstrate a significant improvement in the physical performance of soccer players compared to their pre-training levels.

The results presented in Table 4 indicate a significant difference in the performance factors of speed (P=0.01), agility (P=0.01), and power (P=0.01) between the pre-test and post-test after six weeks of SMST training in the non-ACLR group. These findings demonstrate a significant improvement in the physical performance of soccer players compared to their pre-training levels.

The results presented in Table 5, with pre-test values considered as controls, revealed no significant differences in the records of the Speed test (P=0.63), Agility (P=0.78), and Power (P=0.81) between the ACLR and non-ACLR groups after six weeks of SMST training.

Table 2: Demographic Characteristics of Subjects

Variable	Group	N	Mean±SD
Age(y)	Experimental 1*	Chapter 21	23.23±2.30
	Experimental 2*	Chapter 21	23.19±2.24
Height (cm)	Experimental 1	Chapter 21	179.66±7.26
	Experimental 2	Chapter 21	180.14±4.43
Weight (kg)	Experimental 1	Chapter 21	71.90±8.33
	Experimental 2	Chapter 21	71.52±4.13
BMI* (kg/m^2)	Experimental 1	Chapter 21	22.13±2.39
	Experimental 2	Chapter 21	21.98±1.04

*Experimental 1=with Anterior cruciate ligament (ACLR), Experimental 2=without Anterior cruciate ligament (ACLR), * Body Mass Index (BMI)

Table 3: T-test results in the group with Anterior cruciate ligament (ACLR)

Variable	Mean±SD Pre-test	Mean±SD Post-test	T	P
Speed	4.78±0.18	4.62±0.14	7.04	0.01
Agility	15.75±0.64	0.33±15.16	-13.90	0.01
Power	49.33±4.96	52.96±4.38	7.49	0.01

Table 4: Related T-test results in the group without Anterior cruciate ligament (ACLR)

Variable	Mean±SD Pre-test	Mean±SD Post-test	T	P
Speed	4.73±0.13	4.58±0.10	8.03	0.01
Agility	15.15±0.38	14.95±0.26	4.38	0.01
Power	50.99±4.40	54.13±4.25	-5.60	0.01

Table 5: Results of the covariance analysis test comparing performance outcomes between the ACLR and non-ACLR groups

Variable	Group	Mean±SD Pre-test	Mean±SD Post-test	P	f	Effect size
Speed	Experimental 1	4.78±0.18	4.62±0.14	0.57	6.18	0.63
	Experimental 2	4.73±0.13	4.58±0.10			
Agility	Experimental 1	15.75±0.64	0.33±15.16	0.07	14.63	0.78
	Experimental 2	15.15±0.38	14.95±0.26			
Power	Experimental 1	49.33±4.96	52.96±4.38	0.71	175.36	0.81
	Experimental 2	50.99±4.40	54.13±4.25			

Discussion

The results of this study highlight the impact of the SMST protocol on physical performance factors in both groups of soccer players, with and without ACLR, specifically in speed, agility, and explosive power. After six weeks of SMST training, no significant differences in performance were observed between the groups. This finding indicates that while players with ACLR initially exhibited weaker performance in physical fitness factors compared to those without ACLR in the pre-test, there was no significant difference in the post-test. This demonstrates the positive effect of the SMST protocol on individuals with ACLR.

SMST has the potential to enhance physical performance while simultaneously reducing the risk of knee injuries, particularly ACL injuries. This protocol is a comprehensive approach to improving athletic performance and preventing injuries, making it especially beneficial for soccer players recovering from ACLR.

In soccer, injury prevention training commonly adopts two main approaches: brief warm-up interventions like FIFA 11+, which last up to 20 minutes at the start of a session, and complete pre-season fitness training programs, such as SMST, which last at least 60 minutes. SMST is a comprehensive protocol specifically designed to minimize knee injury risk while enhancing the physical and athletic capabilities of soccer players [18]. While previous studies have primarily investigated the effects of SMST on athletes without neuromuscular impairments, the need to evaluate its impact on soccer players recovering from ACLR led to the initiation of the current research.

One of the fundamental principles of practical training is the principle of training specificity, which emphasizes the alignment between the type of training and the intended performance goal. According to this principle, exercises that closely mimic the target tests or desired movements can have a more significant impact on an athlete's performance [21]. The SMST protocol incorporates various essential components of physical fitness required by soccer players and consists of four key elements: agility and reaction, speed and endurance, plyometric exercises, and strength training [17].

Modern soccer demands high levels of physical fitness, particularly in jumping and sprinting [22]. Plyometric and strength training, key components of SMST, facilitate rapid, motion-based responses during quick joint position changes. They are also instrumental in improving body conditioning and dynamic stability [23]. Plyometric training, characterized by a stretch-shortening cycle, includes vertical and horizontal movements of the center of gravity, which enhances anticipatory postural adjustment [24]. Research has shown that integrating plyometric jump exercises into regular soccer training sessions not only improves physical fitness components such as agility, power, and speed but also reduces injury risks [25].

Plyometric programs have demonstrated significant benefits for elite athletes, including improvements in muscle mass, transitional speed, agility, and explosive lower-limb power. In the current study, the speed performance of soccer players was significantly influenced by SMST training, likely due to the diverse exercises performed across varying distances and conditions on the field [26]. By integrating strength and plyometric training into every session, SMST delivers more substantial performance improvements than alternative training approaches. Previous research on SMST's impact on soccer players without neuromuscular impairments reported a 7% increase in speed, an 18% improvement in power, and a 12% enhancement in agility. The results of our study align with these findings, underscoring that the combined use of agility, speed, strength, and plyometric exercises in each SMST session is the primary driver of these observed performance enhancements.

Agility is a critical determinant of soccer performance, encompassing components such as visual scanning and anticipation, which significantly influence decision-making on the field [27]. Research has shown that plyometric training positively impacts agility by improving the functionality of muscle spindles, Golgi tendons, and tendons, as well as enhancing body posture control [28]. Elite soccer players rely heavily on agility and quick direction changes for optimal performance, as they must rapidly accelerate, decelerate, and pivot throughout a match [29].

The observed improvement in power among athletes in this study may stem from the emphasis on speed and strength training within the SMST protocol. Previous studies on SMST's impact on female athletes in sports such as football, basketball, and volleyball have highlighted its dual benefits: a reduction in injury risks and a significant enhancement in power, with 57% of participants demonstrating notable gains. The training also had a substantial effect on agility [17]. Moreover, a strong correlation has been identified between a team's average vertical jump height and its final placement in the league standings.

Nevertheless, the effectiveness of SMST and other injury prevention protocols on performance has shown variability. Previous investigations have primarily focused on the impact of SMST on athletes without any neuromuscular impairments, concluding that SMST is a highly effective protocol for this category of athletes [18].

However, its efficacy for athletes with neuromuscular deficits and a history of ACLR remains uncertain and underexplored. It is well-documented that a prior ACL injury negatively impacts physical performance. Despite this, the current study's findings demonstrate that SMST significantly and positively enhances physical performance measures in both groups, regardless of whether they had undergone ACLR.

This research was not without its limitations. The study participants were a highly homogeneous group—male soccer players with and without ACLR—which restricts the generalizability of the findings to athletes in other sports or amateur-level soccer players. Furthermore, the lack of controlled nutrition management and the possibility of participants engaging in activities outside the prescribed training regimen may have influenced the results. Another notable limitation was the absence of a proper control group without any intervention, which would have provided a more precise assessment of the protocol's isolated effects on performance.

Conclusion

This research suggests that soccer coaches and players, both with and without ACLR, can integrate the SMST Neuromuscular Injury Prevention Protocol into their team preparation during the season. This protocol has enhanced physical performance and prevented injuries, safeguarding players and reducing the risk of re-injury. Moreover, incorporating SMST into the training programs for elite soccer athletes can elevate the quality of sports performance while ensuring player safety. A mixed training approach, such as SMST, is valuable for improving performance without compromising injury prevention. Based on this study's findings, a preventive training plan can be seamlessly integrated into the overall preparation of soccer players, offering numerous benefits while maintaining high-performance levels.

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