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The Effect of Sportmetrics Soccer Training Program on Postural Control in Soccer Players with and without Previous Anterior Cruciate Ligament Reconstruction

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A B S T R A C T

Objective: The purpose of the present study was to investigate the effect of Sportmetrics soccer training (SMST) program on the center of pressure (CoP) displacement in soccer players with and without anterior cruciate ligament reconstruction (ACLR).
Methods and Materials: The method of this study was a quasi-experimental type, and the number of statistical samples that participated in the present study included 42 soccer players. They were divided into two groups of 21 (with ACLR and without ACLR). The mean, minimal and maximal CoP displacement in anteroposterior (A-P) and mediolateral (M-L) directions was evaluated in both groups before and after six-week of SMST training program. The dependent t-test was used for intra-group comparisons, while a one-way ANOVA test was employed to analyze inter-group differences, with statistical significance defined as ($p \leq 0.05$).
Findings: A significant difference was observed in the mean of (M-L) displacement ($p = 0.021$) in the healthy group between pre-training and post-training. Additionally, significant differences were observed in the mean ($p = 0.011$), minimal ($p = 0.042$) and maximum ($p = 0.013$) ML displacement in the ACLR group between pre-training and post-training. In the post-training assessment, there were no notable discrepancies found in the (M-L) and (A-P) components between the two groups.
Conclusion: Our findings support the premise that a SMST training program during the pre-season alters lower extremity biomechanics in soccer players. Participating in the SMST training program improves postural control in healthy individuals and soccer players with ACLR, potentially reducing the risk of ACL injury or re-injury.
Keywords: *Anterior cruciate ligament (ACL), ACL injury, Knee Injury Prevention, SMST Program, soccer*

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1. Introduction

Soccer is one of the most popular and exciting sports in the world (1). As the sport becomes more popular and the number of participants grows rapidly, the occurrence of sports-related injuries on the field is also increasing (2). "Almost 70% of soccer-related injuries occur in the lower extremities, with the knee being the most commonly affected area"(3). An ACL tear is considered one of the most serious and complex knee injuries, leading to lasting effects such as osteoarthritis, financial strain, proprioceptive deficits, and instability in the knee joint (4).

Many soccer players opt for surgery in order to effectively regain their pre-injury level of performance. ACL reconstruction is considered the most effective treatment for active individuals who have suffered an ACL injury (5). There are numerous studies in the literature that examine the process of return to play (RTP) after ACLR (6, 7). According to recent reports, 86% of elite male soccer players continued to participate in soccer 3 years after ACLR, although only 65% were able to compete at the same level as before their injury (8). Furthermore, studies have shown that the occurrence of re-injury after ACLR ranges from 2% to 19% (9). Additionally, abnormal movement techniques, muscle weakness, and biomechanical deficiencies continue to exist in these athletes even after the standard return-to-sport period of 12 to 60 months (10, 11). The majority of second ACL injuries, like primary ACL injuries, typically happen during noncontact incidents (12). This indicates that deficiencies in neuromuscular and postural control in the lower extremities play a crucial role in the risk of injury. Furthermore, past research has pinpointed postural control deficiencies as a key element leading to re-injury in reconstructed limbs (10, 13). Measuring the displacement of the Center of Pressure (COP) is a typical approach for evaluating postural control. COP displacement has been recognized in previous research as a dependable indicator of postural control. The study conducted by Culvenor and colleagues demonstrated that impairments in COP were still present one year after ACLR (14). Therefore, correcting neuromuscular and postural control deficits in athletes who have had ACL reconstruction surgery may assist them in returning to sports activities in a safe manner.

On the other hand, injury prevention has been one of the most important issues in football in recent years (15). Overall, prevention protocols can be divided into two main groups: neuromuscular training and special warm-up (16). Neuromuscular training (NMT) is considered the best and most effective way to prevent injury and improve performance techniques (17). NMT programs effectively modify biomechanics deficits, improves postural control and reduce the incidence of ACL injuries in athletes. NMT programs differ from traditional strength or balance training by prioritizing sensory-motor enhancement and achieving optimal postural control through a focus on movement quality in all three planes of motion. Petushek et al. concluded that the most successful programs are multi-modal (18). Chappell and Limpisvasti also found that utilizing a NMT can change how motor control strategies are used in specific jumping exercises, leading to enhancements in athletic performance metrics (19). In this context, the SMST protocol has specialized in preventing injuries and enhancing the performance of soccer players (20). SMST offers a variety of training methods that have been used with preventive goals and improving the performance of athletes in previous research (21).

Postural control deficits, a biomechanical variable associated with ACL injury, have not been studied in research influenced by the SMST program in individuals with a history of ACLR. For this reason the purpose of this study was to compare of the effect of SMST Training program on postural control in soccer players with and without ACLR.

2. Methods and Materials

2.1 Study Design and Participants

This study used a pre-test-post-test design in a semi-experimental format. The statistical sample included soccer players from the Premier League as well as the First and Second Divisions. These soccer players were between the ages of 18 and 30 and had a minimum of three years of team training experience. The chosen age range was to reduce the impact of variations in initial training. 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:

- Experience of 3-5 years in soccer club level teamwork and training.

- Subjects in the experimental group had undergone ACL reconstruction surgery.
- No history of diseases related to balance impairment.
- A body mass index (BMI) within the normal range.
- No injuries to the lower limbs, except for ACL injuries, in the last six months.
- The absence of visible abnormalities in the lower limbs (such as anteversion, knock-knees, bowlegs, twisted shin bones, flat feet), as evaluated using the New York test.
- A time period of at least 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 (21).

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.

2.2 Data Collection

At the beginning of the research process, the demographic characteristics of the athletes were recorded and measured. After collecting demographic data, the participants completed a jump and then performed a soccer-specific heading task in the air before landing on a force plate using Double-leg (Figure I). Kinetic data were recorded using a Kistler force plate device at a sampling frequency of 1 kHz. The mean and maximal displacement of the CoP were collected in the ML and AP directions. These variables demonstrated good to excellent reliability, with intraclass correlation coefficients (ICC = 0.73-0.87). 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.

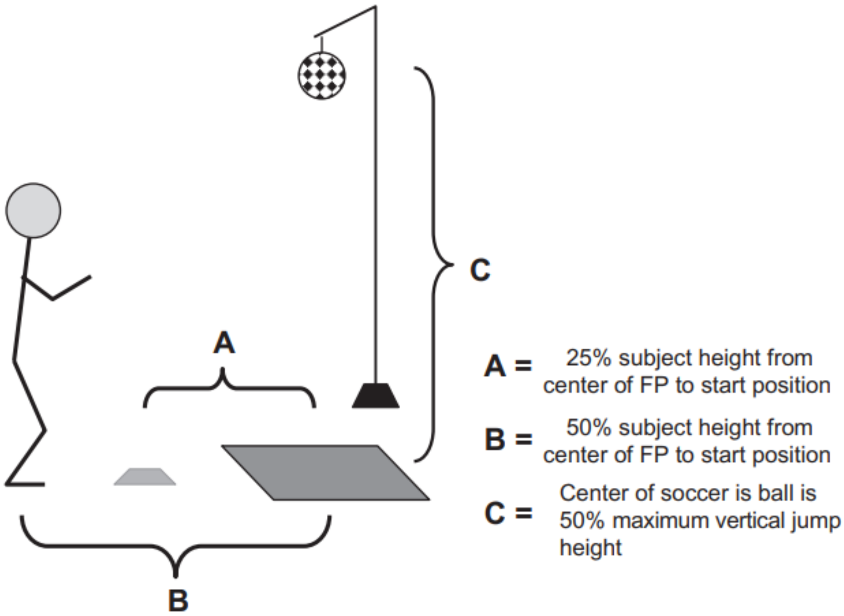

Figure 1. Diagram of subject testing set-up (FP = force plate).

2.3 Sportsmetrics Soccer Training (SMST)

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.

Table 1. Sportsmetrics soccer training program (21)

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.

2.4 Data Analysis

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 anaysis of one-way Analysis of Variance (ANOVA) was used to compare pre-test and post-test differences between the healthy and ACLR groups. Statistical calculations were performed using SPSS version 27, with the significance level at $p \leq 0.05$.

3. Results

The demographic characteristics of the subjects are reported in Table 2.

Table 2. Demographic characteristics of the subjects

Variable	Group	N	Mean ± SD
Age(y)	Experimental 1*	21	23.23±2.30
	Experimental 2*	21	23.19±2.24
Height (cm)	Experimental 1	21	179.66±7.26
	Experimental 2	21	180.14±4.43
Weight (kg)	Experimental 1	21	71.90±8.33
	Experimental 2	21	71.52±4.13
BMI (kg/m^2)	Experimental 1	21	22.13±2.39
	Experimental 2	21	21.98±1.04
Tegner activity scale	Experimental 1	21	7.56±1.73
	Experimental 2	21	8.12±1.39

*Experimental 1= with ACLR, Experimental 2=without ACLR

Table 3 and Table 4 report the results of the dependent t-test in the without ACLR and ACLR group between the pre-test and post-test.

The results in Table 3 show that there is no significant difference in the mean ML displacement (p = 0.021) in the group without ACLR between the pre-test and post-test.

Table 3. Results of the dependent t-test for the without ACLR group

COP	Mean ± SD Pre-test	Mean ± SD Post-test	T	p
minimal displacement (AP*)	93.74±24.85	86.23±21.62	3.84	0.647
minimal displacement (ML*)	176.27±37.56	154.36±30.92	6.38	0.514
maximal displacement (AP)	354.78±19.42	341.66±20.74	4.16	0.863
maximal displacement (ML)	369.43±54.36	347.42±43.50	6.15	0.428
Mean displacement (AP)	178.61±32.47	166.47±29.81	3.94	0.615
Mean displacement (ML)	257.31±53.67	212.61±38.57	8.14	0.021*

AP: center of pressure in antero–posterior direction, ML: center of pressure in medio-lateral direction.

The results in Table 4 show that after six weeks of SMST training, there were significant differences in both the mean (p = 0.011), min (p = 0.042) and maximum (p = 0.013) ML displacement in the ACLR group between the pre-test and post-test.

Table 4. Results of the dependent t-test for the ACLR group

COP	Mean ± SD Pre-test	Mean ± SD Post-test	T	p
minimal displacement (AP)	107.36±30.92	91.96±24.22	4.71	0.234
minimal displacement (ML)	236.72±43.84	169.48±32.31	6.24	0.042*
maximal displacement (AP)	390.89±21.06	357.94±21.17	4.19	0.554
maximal displacement (ML)	427.95±71.67	368.57±33.92	8.47	0.013*
Mean displacement (AP)	217.67±27.32	181.13±26.17	6.98	0.098
Mean displacement (ML)	301.76±59.48	236.39±40.61	9.83	0.011*

The results in Table 5 showed a significant difference in the minimal displacement ML (p = 0.014), maximum ML displacement (p = 0.039), maximal displacement AP (p = 0.018), Mean displacement AP (p = 0.043), Mean displacement ML (p = 0.021) between the groups without ACLR and with ACLR in the pre-test.

Table 5. The results of the one-way Analysis of Variance (ANOVA) test for comparisons between groups in the pre-test.

COP	Mean ± SD Pre-test (without ACLR)	Mean ± SD Post-test (ACLR)	p	F	Effect size
minimal displacement (AP)	93.74±24.85	107.36±30.92	0.466	0.324	0.017
minimal displacement (ML)	176.27±37.56	236.72±43.84	0.014*	7.196	0.531
maximal displacement (AP)	354.78±19.42	390.89±21.06	0.018*	6.862	0.496
maximal displacement (ML)	369.43±54.36	427.95±71.67	0.039*	4.904	0.411
Mean displacement (AP)	178.61±32.47	217.67±27.32	0.043*	3.702	0.364
Mean displacement (ML)	257.31±53.67	301.76±59.48	0.021*	5.108	0.482

The results in Table 6 showed that there were no significant differences in any of the components in the post-test between the two groups ($p \geq 0.05$).

Table 6. The results of the one-way Analysis of Variance (ANOVA) test for comparison between groups in the post-test

COP	Mean ± SD Pre-test (without ACLR)	Mean ± SD Post-test (ACLR)	p	F	Effect size
minimal displacement (AP)	86.23±21.62	91.96±24.22	0.811	0.219	0.011
minimal displacement (ML)	154.36±30.92	169.48±32.31	0.615	0.417	0.016
maximal displacement (AP)	341.66±20.74	357.94±21.17	0.213	1.034	0.123
maximal displacement (ML)	347.42±43.50	368.57±33.92	0.097	2.169	0.217
Mean displacement (AP)	166.47±29.81	181.13±26.17	0.549	0.594	0.039
Mean displacement (ML)	212.61±38.57	236.39±40.61	0.311	0.925	0.175

4. Discussion and Conclusion

We predicted that the SMST program would enhance postural control. The results of the current study showed that an six-week SMST training program can decrease the displacement of the center of pressure (COP) in the anterior-posterior (AP) and medial-lateral (ML) components in soccer players, both with and without anterior cruciate ligament reconstruction (ACLR). A significant difference in maximal ML displacement was observed between the two groups in the pre-test. However, no significant difference was found in the post-test after the six-week SMST training program. This indicates that the SMST training program had a positive effect on both groups, especially in the ACLR group.

It is crucial to have good postural control and stability in soccer to prevent ACL injuries, as the sport involves frequent jumping, landing, and quick changes in direction on one leg due to its dynamic nature. Soccer players who had ACL surgery demonstrated a higher double-leg swing in the pre-test compared to the healthy group in our research. Sugimoto et al, also demonstrated in a study that postural control deficits were significantly greater in the limb that underwent ACL reconstruction compared to the healthy group (22). This change in postural control can result in increased body sway and imbalance in the frontal plane in patients who have undergone ACL reconstruction. When considered as a whole, these findings indicate that evaluating postural stability in the frontal plane could have greater clinical significance (23). On the other hand, when the ACL sustains an injury, the sensory nerves located within the ACL bundle are also damaged. Although ACLR can provide mechanical stability in the knee joint, the nervous system is disturbed and may not be restored for years (24).

Maintaining balance during jump landing requires simultaneous postural control in both the AP and ML dimensions. On the other hand, greater postural instability would likely be indicated by larger deviations in both the AP and ML directions. During research, we found that the postural control deficits were more pronounced in the ML direction during the pre-test compared to the deficits in the AP direction. Changes in the EMG activity of the knee and proximal hip stabilizer muscles post-ACLR have been confirmed in a review of the current literature. These changes could potentially impact postural control during landing tasks.

The literature review reveals several studies examining the impact of NeuroMuscular training (NMT) on postural control. In a study akin to the current research, Paterno et al. found that incorporating 6 weeks of Neuromuscular Training (NMT) with dynamic and plyometric balance exercises led to a notable decrease in Center of Pressure (COP) displacement (25). Compound exercises in athletes have been found to enhance postural control through the activation of afferent-efferent pathways and muscle sensory receptors, as indicated by previous literature reviews (26). In a study conducted by Mayer et al., it was discovered that functional and plyometric exercises had a positive impact on reducing ML center of pressure oscillations in female soccer players performing single-leg jumps on their dominant limb (27). These findings add to existing research and indicate that NMT programs may have the potential to reduce the likelihood of injury.

The individuals involved in this study were athletes who play soccer. Training for soccer must focus on a variety of components to meet the demands of the sport, which requires diverse movements in multiple planes of motion. Intervention programs addressing various movement planes are essential for effectively lowering the risk of ACL injury. NMT focuses on the transverse plane, where ACL injuries commonly happen, in contrast to traditional muscle strength programs that typically target the sagittal or coronal plane. Postural control enhancement after ACLR and NMT may also be credited to brain neuroplasticity. These results suggest that neuroplasticity induced by NMT in ACLR patients may lead to enhanced visual cognition that plays a role in proprioception and postural stability.

Typically, prevention programs run for a duration of 6 to 8 weeks and have shown to be effective (28). According to the research conducted by Zech et al., programs lasting six weeks or more showed a more significant impact on postural control in comparison to programs lasting four weeks (29). In the present study, SMST training was performed for six-week. Malgorzata et al conducted a study examining the impact of 6 weeks of NMT on the postural control of soccer players, similar to the present study. The findings indicated that ML COP displacement was significantly decreased after 6 weeks of multi component training (23).

Our findings indicate that altering biomechanical and neuromuscular risk factors may play a key role in the effectiveness of injury prevention programs aimed at reducing ACL tears, regardless of the specific cause of the change in postural control following training. The ACL injury prevention training program utilized in this study has been shown to effectively reduce the incidence of ACL injuries in soccer players, making our findings particularly compelling. Participating in a six-week SMST training program revealed biomechanical alterations that may help prevent ACL injuries. Our findings suggest that the protective effect provided by ACL injury prevention training may be achieved through improved postural control. Sports coaches have the option to utilize the SMST training program in order to avoid ACL injury or re-injury, as per the provided materials.

In conclusion, our results support the use of the SMST Program, or a similar program, for clinicians who want to enhance lower extremity mechanics and improve postural control. Participating in a 6-week SMST training program before the season improves postural control in both soccer players with and without ACL reconstruction while performing a landing task. This may explain the protective effect of this training program on preventing ACL injuries or re-injuries.

It is important to acknowledge the various limitations of the current study. We did not control the lifestyle of any of the participants, such as sleep and exhaustion from studying, which may affect the results. Future studies should expand their focus beyond just soccer players and include athletes from various sports involving landing, such as volleyball and basketball.

Authors' Contributions

A. S. H. was responsible for the study design and the original draft writing. Y. S. contributed to data collection. Y. H. conducted the results analysis. P. S. and H. D. were involved in both the results analysis and the review and editing of the manuscript.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human 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.

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