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The Prevent Injury and Enhance Performance Training Program Enhances Postural Control in Soccer Players with and without Anterior Cruciate Ligament Reconstruction

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SUMMARY

Objective. The purpose of the present study was to investigate and compare the effect of prevent injury and enhance performance (PEP) training program on the center of pressure (CoP) displacement in soccer players with and without anterior cruciate ligament reconstruction (ACLR).

Materials and methods. Twenty-one soccer players (male; median age 25.43 years) 15.12 months post- ACLR, and twenty-one healthy soccer players (male; median age 22.79 years) underwent postural control assessment during a single-leg landing task. The mean and maximal CoP displacement in anteroposterior (A-P) and mediolateral (M-L) directions was evaluated in both groups before and after eight-week of PEP training program. Differences in all variables were analyzed using a 2 (group) × 2 (time) repeated measures ANOVA, with statistical significance set at ($p \le 0.05$).

Results. A significant difference was observed in the mean of (M-L) displacement ($p = 0.002$) in the healthy group between pre-training and post-training. Additionally, significant differences were observed in both the maximal ($p = 0.027$) and mean of (M-L) displacement ($p = 0.003$) in the ACLR group between pre-training and post-training. The comparison between groups in the pre-training showed a significant difference in the maximal (M-L) displacement ($p = 0.011$) between the two groups. No significant differences were observed in the (M-L) and (A-P) components between the two groups in the post-training assessment.

Conclusions. Our findings support the premise that a PEP training program during the pre-season alters lower extremity biomechanics in soccer players. Participation in PEP training program improves postural control in both healthy and ACLR soccer players, which may explain the protective effect of this type of training program in reducing the risk of anterior cruciate ligament (ACL) injury or re-injury.

KEY WORDS

Anterior cruciate ligament (ACL); ACL injury; knee injury prevention; PEP program; soccer.

INTRODUCTION

One of the highest intensity sports that is being played every day throughout the world is soccer. With the growing popularity of the sport and the rapid growth of the number of subjects, particularly in youth divisions, the prevalence of sports-related injuries on the field is also rising (1). Nearly 70% of soccer-related injuries occur in the lower extremities, with the knee being the most commonly affected site

(2). One of the most severe and complex knee injuries is an anterior cruciate ligament (ACL) tear. This injury often results in long-term consequences such as osteoarthritis, financial burden, proprioception deficits, and knee joint instability (3).

Most soccer players opt for surgical treatment to safely return to their pre-injury level of performance. Anterior cruciate ligament reconstruction (ACLR) is considered the gold standard treatment for active patients with an ACL injury (4). Recent research continues to demonstrate a relatively low rate of return to pre-injury levels of play among athletes following ACLR (5, 6). Recently, it was reported that 86% of elite male soccer players still played soccer 3 years after ACLR, but only 65% competed at their pre-injury level (7). Additionally, recent studies indicate that the rate of re-injury and subsequent ACL injury among young athletes ranges from 24% to 29% (8, 9).

Furthermore, aberrant movement strategies, muscle weakness, and biomechanical deficits persist in these athletes even beyond the typical return-to-sport timeframe of 12 to 60 months (10, 11). Similar to primary ACL injuries, the majority of second ACL injuries occur as noncontact episodes, suggesting that neuromuscular and postural control deficits in the lower extremities are significant risk factors. Additionally, previous studies have identified postural control deficits as one of the primary factors contributing to re-injury in the reconstructed limbs (10, 12). A common method for the characterization of postural control is to quantify the displacement of the center of pressure (CoP) (13). Previous studies have identified CoP displacement as a reliable measure for assessing postural control (14-16). In this regard, the study conducted by Culvenor *et al*. (17) demonstrated that CoP deficits persisted 12 months after ACLR. Therefore, correction neuromuscular and postural control deficits in athletes with ACLR may enable them to safely return to sport.

Neuromuscular training (NMT) programs effectively modify biomechanics deficits, improves postural control and reduce the incidence of ACL injuries in athletes (18). Unlike traditional strength or balance training, NMT programs are designed to enhance sensory-motor and achieve optimal postural control by focusing on movement quality across all three planes of motion (19). Yarsiasat *et al.* (20) concluded that the most successful programs are multi-modal and include a focus on enhancing strength, plyometric, balance, flexibility, and jump-landing stabilization. Furthermore, Chappell and Limpisvasti reported that the implementation of a NMT can alter motor control strategies in select jumping tasks and improve athletic performance measures (21).

In this context, the Santa Monica Orthopedic and Sports Medicine Research Foundation designed the Prevent Injury and Enhance Performance (PEP) Program in 1999 (22). This program includes warm-up, strengthening, stretching, plyometric, and agility exercises designed to address neuromuscular deficits and enhance the stability of the muscles surrounding the knee joint. Additionally, PEP program does emphasize instruction in movement mechanics (*i.e.*, “soft landing” and “ preventing knee valgus”) (23). Previous studies have reported enhanced performance following participation in the PEP training program (24, 25). For instance, Lim *et al.* (26) demonstrated improvements in muscle strength and flexibility. Furthermore, other studies have reported improvements in landing technique and muscle imbalances after participation in the PEP training program (25, 27).

In addition to enhancing performance, this program has been shown to reduce the risk of ACL injuries in athletes, particularly those with a history of ACL injury (22). However, it remains unclear whether the reduction in ACL injury incidence is solely attributable to improvements in strength, balance, or other performance-related characteristics, or whether biomechanical factors such as enhanced postural control following PEP training also contribute to this reduction. Furthermore, Mandelbaum *et al.* (23) suggested that future studies should investigate the biomechanical mechanisms underlying the effects of the PEP training program on reducing the incidence of ACL injuries in athletes. However, current evidence indicates that biomechanical variables associated with ACL injury, such as postural control deficits, have received limited attention in research following the implementation of the PEP program. For this reason the purpose of this study was to compare of the effect of PEP Training program on postural control in soccer players with and without ACLR.

METHODS

This study followed a longitudinal semi- experimental trial with convenience sampling. The statistical population of the present study consisted of professional soccer players from 15 teams in the first and second division leagues of the country. Sample size calculation was performed with G*Power which determined that 21 subjects would be necessary to detect a statistical difference in each group given an estimated effect size of a power set at 0.80 and $\alpha = 0.05$. A P-value significance level was set at 0.05 (28). 42 soccer players were selected as the statistical sample using purposive and convenience sampling methods. The participants in this study were divided into two groups: an ACLR group (n = 21) and a healthy control group (n = 21). Participants in the ACLR group consisted of 21 male soccer players who had undergone surgery: 17 with ACLR in the dominant limb and four with ACLR in the non-dominant limb).

The time since the participants' surgery was 6 to 18 months (mean 15.12 ± 3.86) and their age ranged from 20 to 30 years. Additionally, all participants had a minimum of three years of soccer experience. Exclusion criteria included: 1) previous knee injury or surgery (except for ACL injury), 2) re-injury or re-surgery in the ACLR knee, 3) injury or surgery in the contralateral knee, 4) Other conditions that affect daily functioning (*e.g.*, visual or vestibular disorders that may impact balance), 5) knee pain within the last three months, and (6) non-participation in more than three sessions or two consecutive sessions of the PEP training program.

The present study was approved by the Ethics Committee of the Iranian Research Institute of Physical Education and Sport Sciences (approval code: SSRI.REC-2312-2560 – date of approval: February 29, 2024).

Procedures

All tests were conducted under the supervision of a sports and biomechanics laboratory expert. Demographic data, including age, height, weight, body mass index (BMI), and Tegner activity scale (TAS), were collected from all 42 participants. After demographic data collection, participants performed a jump and, following a soccer-specific jump heading task, landed on the force plate using a single leg. Kinetic data were recorded using a Kistler force plate device at a sampling frequency of 1 kHz. The mean and maximal displacement (mm) 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) (29).

Jumping and landing task

Subjects were asked to start at a position that was half of their body height away from the center of the force plate. They were then asked to jump over a 7.5-cm cone, which was placed halfway between the start position and the force plate. The subjects were then instructed to perform a jump header (the center of the ball was kept stationary and positioned above the head of the subject at 50% of the subject's maximum jump height) and then perform single leg landing (**figure 1**) (30). Also, the subjects were asked to remain on one leg for ≥ 5 seconds after landing (31). If the opposite leg came in contact with either the floor or the leg being tested, the trial was terminated. No further landing instructions were provided since this study aimed to quantify the inherent postural strategy of individuals. The gaze point was not specified during landing for safety reasons (32).

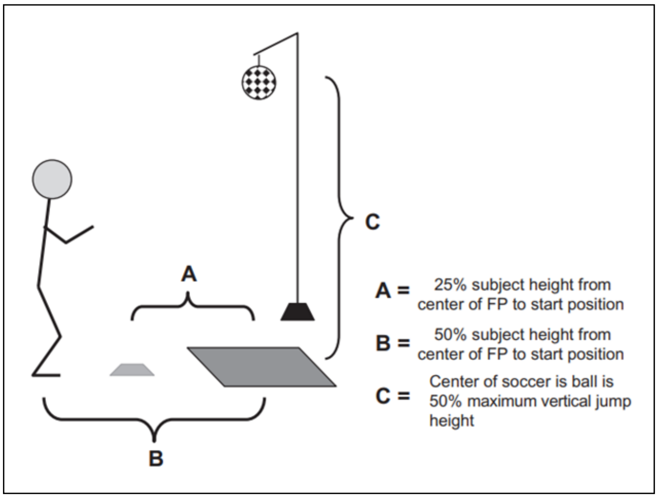

Figure 1. Diagram of subject testing set-up.
FP: force plate.

Tegner activity scale (TAS)

Tegner activity scale (TAS) was used to check the activity level of ACLR patients. The TAS was designed as a score for activity level to complement the functional knee score for patients with ACL injuries. The instrument scores a person's activity level between 0 and 10 where 0 is 'on sick leave/disability' and 10 is 'participation in competitive sports such as soccer at a national or international elite level'. Pertinently, activity levels 6-10 can only be achieved if a person takes part in recreational or competitive sports (33).

Data Processing

Kinetic data were analyzed using Nexus 1.8.5 and Visual3D software. Kinetic data were smoothed using a fourth-order Butterworth filter with a cutoff frequency of 20 Hz and normalized to the subject's body weight (34). AP displacement is the range of CoP movement in the AP direction, and ML displacement is the range of CoP movement in the ML direction. CoP measurement on force plate during jumping and landing were conducted three times for each person, and the average value of three trials was analyzed. In this study, the maximum and mean displacement of the CoP in two M-L and A-P directions were analyzed.

PEP training program

The PEP training program consists of five components:

Table I. PEP* training program.

Phase	Activity (Duration of Time to Complete Activity)	Time at Which Activity	Purpose
1.Warm–up (purpose: preparation)	Jog line-to-line (30 sec)	0 to 0.5 min	Prepare for training session
	Shuttle run (side-to side) (30 sec)	0.5 to 1 min	Engage hip abductors and adductors; promote speed; avoid inward caving of knee joint
	Backward run (30 sec)	1 to 1.5 min	Engage hip extensors and hamstrings
2. Strengthening (purpose: leg strength)	Walking lunges (1 min)	1.5 to 2.5 min	Strengthen quadriceps
	Russian hamstring (1 min)	2.5 to 3.5 min	Strengthen hamstrings
	Single toe raises (1 min)	3.5 to 4.5 min	Strengthen calf; improve balance
3. Plyometrics (purpose: power, strength, speed)	Lateral hops over cone (30 sec)	4.5 to 5 min	Increase power and strength; emphasize neuromuscular control
	Forward and backward hops over cone (30 sec)	5 to 5.5 min	Increase power and strength; emphasize neuromuscular control
	Single leg hops over cone (30 sec)	5.5 to 6 min	Increase power and strength; emphasize neuromuscular control
	Vertical jumps with headers (30 sec)	6 to 6.5 min	Increase vertical jump
	Scissor jump (30 sec)	6.5 to 7 min	Increase vertical jump
4. Agilities	Forward run with 3-step deceleration	7 to 8 min	Increase dynamic stability of ankle-knee-hip complex
	Lateral diagonal runs	8 to 9 min	Encourage technique and stabilization of hip and knee; avoids “knock-knee” position
	Bounding run (44 yd)	9 to 10 min	Increase hip-flexion strength, power, and speed
5.Stretching (can be performed after warm-up)	Calf stretch (30 sec × 2 repetitions)	10 to 11 min	Stretch calf; focus on lengthening muscle
	Quadriceps stretch (30 sec × 2 repetitions)	11 to 12 min	Stretch quadriceps; focus on lengthening muscle
	Figure four hamstring stretch (30 sec × 2 repetitions)	12 to 13 min	Stretch hamstrings; focus on lengthening muscle
	Inner thigh stretch (20 sec × 3 repetitions)	13 to 14 min	Stretch adductors; focus on lengthening muscle
	Hip flexor stretch (30 sec × 2 repetitions)	14 to 15 min	Stretch hip flexors; focus on lengthening muscle

PEP*: Prevent injury and Enhance Performance.

warm-up, strength training, plyometric, agility exercises, and stretching (35) (**table I**). Both healthy and ACLR groups performed PEP training for eight-week and three sessions a week. The duration of each session in the protocol ranged from 15 to 20 minutes. Additionally, the PEP training program include verbal feedback to correct movement patterns. Coaches and trainers should emphasize correct posture, vertical jumps without excessive lateral movement, and reinforce soft landings. For this reason, the correct training techniques were explained to the players during a one-hour instructional session. The necessary equipment for performing the exercises included cones and agility obstacles. It is important to note that these exercises were conducted during the pre-season period, prior to the start of competitions.

Statistical analysis

The Shapiro-Wilk test was used to assess normality for all

Table II. Demographic characteristics.

Variable	Healthy (n=21) Mean ± SD	ACLR (n=21) Mean ± SD
Age (y)	22.79 ± 2.09	25.43 ± 2.20
Height (cm)	182.29 ± 24.14	180.54 ± 20.31
Weight (kg) BMI*(kg/m²)	74.66 ± 7.29	74.32 ± 6.93
Time since surgery (mo)	N/A	15.12 ± 3.86
Tegner activity scale	8.43 ± 2.81	7.59 ± 3.33
Injured limb (Dominant Limb)	N/A	17

BMI*: Body Mass Index.

Table III. Changes in postural control variables (mean ± SD).

Variable		Healthy (n = 21) Mean ± SD		ACLR (n = 21) Mean ± SD
Maximal displacement (A-P)	Pre. test	283.44 ± 23.44	G=0.22	316.44 ± 16.44
(mm)	Post. test	256.71 ± 20.18	T=0.001	281.71 ± 22.18
	Effect size	0.53 (-0.42, 0.98)	G×T=0.001	0.81 (-0.13, 1.22)
Maximal displacement (M-L)	Pre. test	343.73 ±36.09	G=0.41	387.73 ± 44.28
(mm)	Post. test	303.68 ± 9.41	T=0.001	318.68 ± 29.90*,**
	Effect size	0.64 (-1.08, 0.18)	G×T=0.001	1.26 (0.41, 1.92)
Mean displacement (A-P)	Pre. test	209.76 ± 25.63	G=0.11	246.76 ± 23.84
(mm)	Post. test	187.76 ± 18.78	T=0.001	202.76 ± 35.00
	Effect size	0.71 (-0.12, 1.25)	G×T=0.001	1.26 (-0.36, 1.60)
Mean displacement (M-L)	Pre. test	233.65 ± 49.79	G=0.32	297.65 ± 61.79
(mm)	Post. test	194.46 ± 53.01*	T=0.001	229.46 ± 52.01*
	Effect size	0.89 (-1.08, 0.23)	G×T=0.001	1.56 (-0.91, 2.16)

*Significant difference between pre-test and post-test; **significant difference between Healthy and ACLR groups; G: Group effect; T: Time effect; G×T: Group × Time interaction effect; A-P: Anteroposterior; M-L: Mediolateral; ACLR: Anterior Cruciate Ligament Reconstruction.

measured values. Differences in all variables were analyzed using a 2 (group) × 2 (time) repeated measures ANOVA. When a significant F-value was achieved across time or groups, Bonferroni *post-hoc* procedures were performed to identify the specific pairwise differences. Additionally, the effects of training (effect size (36) were calculated using Cohen's d (37) Statistical analysis was performed using IBM SPSS version 26.0 software with a significance level of $p \leq 0.05$.

RESULTS

The demographic characteristics of the subjects are reported in **table II**.

The results indicated a significant difference in the maximal ML displacement ($p = 0.001$) between the healthy and ACLR groups in the pre-test. Also, the results showed no significant differences in any of the components in the post-test between the two groups ($p \geq 0.05$) (**table III**).

Furthermore, the results indicate a significant difference in the mean ML displacement ($p = 0.001$) in the healthy group between the pre-test and post-test. Additionally, the results demonstrate that after eight weeks of PEP training, there were significant differences in both the mean ($p = 0.001$) and maximal ($p = 0.001$) ML displacement in the ACLR group between the pre-test and post-test (**table III**).

DISCUSSION

The purpose of this study was to examine the effect of preventing injury and enhance performance training program on postural control in soccer players with and without anterior cruciate ligament reconstruction. The results of the present study demonstrated that eight-week PEP training program can reduce the CoP displacement in the A-P and M-L components in soccer players, with and without ACLR. Although there was a significant difference in maximal ML displacement between the two groups during the pre-test, no significant difference was observed in the post-test following the eight-week PEP training program. This indicates that the PEP training program had a positive effect on the ACLR group.

Most current prevention programs last between 6 to 8 weeks and have been proven to be effective (38). In the present study, PEP training program was performed for eight-week. It appears that six weeks correlates with the time frame needed to increase motor recruitment, but it does not correlate with what is needed for muscle hypertrophy or improved endurance. In this regard, in a study similar to the present study, Lemos *et al.* investigated the effects of 6 weeks of NMT on the postural control of soccer players. The results showed that 6 weeks of multi component training significantly reduced ML CoP displacement (41). Unlike our study, in this study, the AP CoP displacement was also significantly reduced. Webster *et al*. reported comparable findings in a study involving soccer players. In this investigation, the training group underwent two months of resistance, balance, and strength exercises. Following this intervention, a significant reduction in the components of CoP was observed, indicating the effectiveness of the exercise regimen in improving postural control (42). However, certain studies in the literature do not corroborate the efficacy of NMT in enhancing postural control. For instance, the study conducted by McKeon *et al*. indicated that six weeks of balance exercises failed to produce any significant changes in the postural stability of 31 adult men across all components of CoP. This suggests that the effectiveness of NMT may vary depending on specific conditions or populations (38). Similarly, the study by Verhagen *et al*. showed that a 5.5-week balance exercise program had no effect on any of the CoP fluctuation components (39).

Given the dynamic nature of soccer, which includes frequent jumping, landing, and rapid directional changes on a single leg, maintaining postural control and stability is crucial for minimizing the risk of ACL injuries. In our study, soccer players who had undergone ACLR exhibited greater single-leg swing in the pre-test compared to the healthy group. The study by Sugimoto *et al*., which investigated single-leg postural stability following ACLR, reported findings consistent with those of the present study (40). Specifically, they demonstrated that postural control deficits in the ACLR limb were significantly greater compared to those in the healthy group. Additionally, studies also demonstrated that postural control deficits in the injured limb were significantly greater compared to the contralateral limb (17, 40). Single-leg stability deficits after ACLR may be explained by sensory nerve deficits. When the ACL is injured, the sensory nerves within the ACL bundle are also torn. Although ACLR can provide mechanical stability in the knee joint, the nervous system is disturbed and may not be restored for years (17). On the other hand a recent study found that injured limbs not only generated lower torque but also exhibited higher force complexity (sample entropy, SE), indicating less efficient motor patterns. This altered SE correlated with poorer hop test performance (41). These findings suggest that postural control deficits in ACLR patients may stem from combined strength loss and impaired neural coordination.

Maintaining balance during jump landing requires simultaneous postural control in both the AP and ML dimensions. On the other hand, larger deviations in both the AP and ML directions would likely indicate greater postural instability. In our study, the postural control deficits in the ML direction during the pre-test were greater than those in the A-P direction. The study by Culvenor *et al.* (17) showed the larger ML direction deficits observed following ACLR likely reflect the greater demands placed on the control of M-L knee movement during a single-leg landing. While we did not investigate knee valgus in the present study, knee valgus was more observed in ACLR group compared to healthy subjects during landing (42). On the other hand, a review of the existing literature confirms changes in the EMG activity of the knee and proximal hip stabilizer muscles following ACLR, which may contribute to altered postural control during unipodal tasks (43). This alteration in postural control may lead to increased body oscillation and imbalance in the medio- lateral plane of movement (frontal plane) in ACLR patients.

The participants in the present study were soccer players. Soccer involves multi-plane movements and requires multi-component training across various planes of motion. Indeed, intervention programs that target multiple planes of movement are necessary to effectively reduce the risk of ACL injury. While, regular muscle strength programs usually work on the sagittal or coronal plane, PEP program also works on the transverse plane, where ACL injuries usually occur. For this reason, recent studies have tried to establish an association between NMT and an improvement in postural control in a variety of populations, of which populations with chronic ankle instability and ACL injuries are the most common (44, 45). The improvement in postural control following ACLR and after PEP program can also be attributed to brain neuroplasticity. In their research, Chaput *et al*. (46) found that in the ACLR group, NMT can improve visual cognition. On the other hand, visual memory was associated with neural activity in the cerebral cortex, but no neural correlates were observed in the control group. These findings indicate that PEP training program in ACLR patient may induce unique neuroplasticity that results in visual cognition contributing to proprioception and postural stability to a degree that healthy controls do not require. While our PEP program improved dynamic postural control, recent work suggests conventional proprioception tests like passive knee joint position sense (JPS) may lack sensitivity to detect these functional gains. Jebreen *et al*. (47) found no significant JPS differences between ACL-reconstructed and healthy knees, despite known postural deficits in ACLR patients. This discrepancy highlights that PEP's benefits - observed in our CoP measures - likely reflect integrated neuromuscular control rather than isolated joint position awareness, further supporting the need for task-specific assessments like ours.

Regardless of the cause of the observed post-training change in postural control, our results point to the modification of biomechanical/neuromuscular risk factors as being a potential mechanism by which injury prevention programs are successful in decreasing ACL tears. Our findings are particularly compelling because the ACL injury prevention training program implemented in this study has been shown to reduce the incidence of ACL injuries in soccer athletes. We found that participation in an eight-week PEP training program resulted in biomechanical changes that may be considered to be "ACL protective". Our findings suggest that the protective effect afforded by ACL injury prevention training may be achieved through improved postural control. According to the mentioned materials, sports coaches can use the PEP training program to prevent ACL injury or re-injury. Additionally, as highlighted in the study by Pollard *et al*., the PEP training program can optimize biomechanical deficits during landing after injury, subsequently reducing the risk of injury (27).

Limitations and research suggestions

The present study has several limitations that should be considered. We did not control the lifestyle of any of the participants, for instance sleep and exhaustion from study, which may affect the results. Additionally, we did not account for different ACL graft types (*e.g*., hamstring autograft, patellar tendon, allograft), which could influence rehabilitation outcomes. An additional limitation of the current study was that it was limited to soccer players: future studies should consider including athletes from different cutting and landing sports such as volleyball and basketball (20, 48). Finally, athlete satisfaction and functional improvements were not addressed during the present study.

CONCLUSIONS

Our findings support the implementation of the PEP training Program, or a similar program, for clinicians aiming to improve lower extremity mechanics and improve postural control. Participation in an 8-week PEP training program in the preseason improves the postural control in both ACLR and healthy athletes while perform a landing task, which may explain the protective effect of this type of training program on injury or re-injury of ACL.

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DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

ASM: conceptualization. MM: data curation. M G: writing – original draft, writing – review & editing, formal analysis. HD: formal analysis.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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