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The Effect of a Neuromuscular Training Program on Landing Kinematics in Young Soccer Players with Poor Landing Mechanics

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ABSTRACT

Background: This study aimed to investigate the impact of the Prevent Injury and Enhance Performance (PEP) program on knee valgus and knee flexion angles, as well as Landing Error Scoring System (LESS) test scores in young male soccer players with poor landing mechanics. The study identified how increased knee valgus, decreased knee flexion and poor landing patterns contribute as risk factors for these young athletes' anterior cruciate ligament (ACL) injuries.
Methods: The present study utilized a quasi-experimental design. A total of 47 soccer players with poor landing mechanics were purposefully recruited and randomly assigned to either the intervention group (n=23 players, age=12.69±0.70 years, height=1.53±0.06 m, weight=49.91±6.76 kg) or the control group (n=24 players, age=12.55±0.64 years, height=1.51±0.08 m, weight=51.25±7.73 kg). The study measured Knee Valgus angle, Knee flexion angle, and LESS test scores at the baseline and the end of the 8-week study period. During the study, the intervention group used the Prevent Injury and Enhanced Performance (PEP) program as a warm-up routine, while the control group continued with their regular warm-up routine. The researchers used ANCOVA (Analysis of Covariance) and paired-sample t-test statistical analyses to evaluate the changes.
Results: the intervention group significantly reduced knee valgus angle (P=0.001). Additionally, there were significant enhancements in knee flexion angle (P=0.003) and the LESS test scores (P=0.001). In contrast, the control group did not show significant improvements in knee valgus and knee flexion angles (P>0.05), except for LESS test scores (P=0.001), where they also demonstrated improvement. Moreover, the study found significant differences between the intervention and control groups in knee valgus angle (P=0.001), knee flexion angle (P=0.025), and LESS test scores (P=0.001).
Conclusion: This study demonstrated that the PEP program effectively reduced dynamic knee valgus angles, increased knee flexion angles, and improved LESS test scores in young male soccer players. Therefore, it appears that this program can reduce the risk of ACL injuries in this population.

Introduction

Soccer is undeniably one of the most popular sports worldwide, attracting many athletes and fans alike [1]. A significant proportion of soccer players globally are under 18, indicating its popularity among children and preadolescents [1]. While soccer offers numerous health benefits for young individuals, it also increases the risk of sports-related injuries, especially during training and matches [2]. Among the various injuries, lower extremity injuries are particularly common in preadolescent soccer players, with reported rates ranging from 2.3 to 6.4 cases

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per 1000 hours of athlete exposure, peaking at the age of 13 years [3].

Of great concern is the rising trend of anterior cruciate ligament (ACL) injuries among children and preadolescents [4]. These severe injuries can have significant physical and psychological consequences for young athletes [4]. Given the severity of ACL injuries and their potential long-term impact, it is imperative to identify the contributing factors and implement effective training programs to prevent such injuries in young soccer players.

Neuromuscular and biomechanical factors are internal variables that can be modified to reduce the risk of non-contact ACL injuries [5]. Studies have identified trunk dominance, ligament dominance, quadriceps dominance, and leg dominance as underlying mechanisms contributing to ACL injuries [5]. Among these, ligament dominance, leading to valgus defect, is particularly common and can result in abnormal hip and tibial movements during landing and cutting tasks, increasing the stress on knee ligaments and raising the risk of ACL injuries [5]. Notably, 13-year-old soccer players have shown the highest rate of knee valgus, and injured players tend to exhibit excessive dynamic knee valgus during landing [6, 7].

Insufficient knee flexion during landing can also increase ligament strain, indicating the importance of neuromuscular control in avoiding risky body positions associated with ACL injuries [7, 8]. Tests like the Drop-Jump and Landing Error Scoring System (LESS) have demonstrated associations between movement control deficits and an elevated risk of lower extremity and ACL injuries [9, 10]. Young soccer players with LESS scores of 5 or more are found to be at greater risk of sustaining non-contact ACL injuries compared to those with scores below 5 [9].

In response to these injury risks, various injury prevention and neuromuscular training programs, including the Prevent Injury and Enhance Performance (PEP) program, have been developed [11]. The PEP program is a neuromuscular training regimen that replaces the standard warm-up routine. It targets trunk muscle endurance, strength, balance, and agility while emphasizing proper biomechanical movement patterns [11].

Mandelbaum et al. [11] studied the effects of implementing the PEP program in soccer players who performed the program 2-3 times a week for 12 weeks. The results showed an 88% reduction in ACL injury rate in the intervention group in the first year and a 74% reduction in the second year. Another study [12] reported that the PEP program could decrease the risk of ACL injury by 41%. However, the results of studies on implementing injury prevention programs in youth are contradictory [13]. Root et al. [14] used injury prevention exercises to improve jump-landing patterns, but although some improvement was found, no significant differences between groups were observed in the scores of the LESS test. The mechanisms of neuromuscular training programs are not fully defined; therefore, further research is needed to study the influencing mechanism of these programs. Additionally, it is currently unknown if young male soccer players who perform the PEP program can improve landing kinematics, such as knee valgus, knee flexion angle, and LESS scores.

Methods

Study Design and Participants

The present study employed a quasi-experimental design, with young male soccer players exhibiting poor landing mechanics as the statistical population. The participants were selected from Shahrdari Rasht soccer academy, and 127 soccer players were initially considered for eligibility. Written information about the study was provided to the parents, who gave their written informed consent before the study commenced. To be included in the study, the players had to be between 12 to 13 years old, healthy, and meet the criteria of having a dynamic knee valgus angle >15° during the drop vertical jump test [1] and poor jump-landing biomechanics with a LESS score >6 [9] in 2D video analysis. Ultimately, 50 soccer players met the inclusion criteria and were purposefully recruited to participate in the study.

Using computer-based random numbers, the participants were randomly assigned to either the intervention (INT, n=25) or control (CON, n=25) group. Two players from the INT group and one from the CON group withdrew from the study before completing the post-test, leaving 47 players in each group for the final analysis. All participants had at least three years of experience in soccer training and games.

During the 8-week intervention period, the participants completed three training sessions per week in the afternoon. The INT group performed the Prevent Injury and Enhanced Performance (PEP) program as a warm-up before each training session, while the CON group followed their usual warm-up routine. The usual warm-up program involved players moving around within a small area, practicing various dribbling and passing techniques, and performing lower extremity stretching exercises. Both warm-up programs lasted for 20 minutes and were implemented by an experienced research team member.

The participants were assessed twice, before and after the 8-week training period. The study followed the ethical standards of the Declaration of Helsinki and was approved by the Research Ethics Committee of the Sport Sciences Research Institute in Iran (Ethics approval number: IR.SSRC.REC.1400.052).

Knee Valgus and Knee Flexion Assessment

In this study, the knee valgus and knee flexion angles were assessed using the drop vertical jump (DVJ) test [15] (Figure 1). To perform the DVJ test, each participant stood with their feet shoulder-width apart on a 50 cm high box. They then performed a drop-jump by jumping off the box, landing on a predetermined area before it, and immediately performing a maximum vertical jump. The participants practiced the test three times to become familiar with the process before performing it twice for data collection. They were allowed to rest for one minute between jumps.

Figure 1: Assessment of knee valgus and knee flexion angles

To capture the DVJ test, the authors positioned two digital video cameras (Casio Exilim Pro EX-F1, Japan) in the sagittal and frontal planes at a height of 100 cm and a distance of 365 cm from the jump box [15]. The tests were recorded at 60 frames per second. The free available software Kinovea 0.8.15 (USA) was used to evaluate the landing technique. The peak knee flexion was identified for each video as a reference point to estimate the knee valgus and flexion angles. The participants' introduction synchronized the films, and the cameras recorded simultaneously. Adobe Premiere Pro (v1.1.6.1316) was used to synchronize the frames.

The researcher reviewed the performances, frame by frame, in both the sagittal and frontal planes simultaneously in Kinovea software to find the peak knee flexion and measure the knee valgus angle. The kinematic data were recorded at 60 fps. No markers were used for landing kinematic analysis to ensure the data reduction process was more time-efficient and generalizable for applied settings. Previous research has shown that this method has excellent reliability (ICC>0.9) [16].

This study assessed knee valgus and knee flexion angles for the dominant leg by measuring the angles at peak maximum knee flexion. Peak knee flexion was defined as the frame immediately before the subject increased knee extension to perform the maximum vertical jump. The dominant leg was defined as the leg with which the participant could kick a ball the furthest.

For the knee valgus angle, the researcher measured the angle formed by the intersection of a straight line that bisected the thigh outline and a straight line that bisected the borders of the lower leg [16]. The knee flexion angle was measured as the angle formed by straight lines joining the lateral femoral epicondyle and the lateral malleolus [16]. The mean knee valgus and knee flexion angles from the DVJ trials were used for further analysis in the study.

Landing Error Scoring System (LESS)

The Landing Error Scoring System (LESS) is a standardized field-movement assessment tool to identify faulty movement patterns. Studies have shown that LESS has concurrent validity against 3-dimensional motion analysis and good interrater reliability with an ICC of 0.91 [9, 17]. The LESS test score measures landing pattern errors, and a higher LESS score indicates a poorer landing pattern.

The LESS consists of 17 scored items, assessing different landing technique aspects. Items 1 to 6 assess the lower limbs and trunk condition at initial contact with the ground. Items 7 to 11 assess positioning errors of the feet. Items 12 to 15 assess lower limb and trunk movements between initial contact and the moment of maximum knee flexion. The last two items, 16 and 17, evaluate the overall movement quality [9, 17].

Participants in the study were divided into four quartiles based on their LESS score, representing different levels of jump-landing biomechanics: excellent (LESS score≤4), good (LESS score>4 to ≤5), moderate (LESS score>5 to ≤6), and poor (LESS score>6) jump-landing biomechanics [9].

To complete the LESS test, the players performed a forward jump from a 30-cm high box to a strip of tape placed on the ground at a distance of half of each subject's height. After landing on both feet, the participants were instructed to jump vertically at maximal height and land approximately in the same location. Before the data collection, the participants had two practice trials to perform the task correctly. Subsequently, the players performed three successful trials of a standardized drop vertical jump task.

Two digital video cameras (Casio Exilim Pro EX-F1, Japan) were positioned 345cm in front of and to the side of the subjects to record the jump-landing trials. The mean scores of the three jumps were recorded as the final LESS score for each player, which was used for further analysis in the study [9, 17].

Intervention

The Prevent Injury and Enhance Performance (PEP) program is a neuromuscular training program designed to address potential deficits in strength and coordination of the stabilizing muscles around the knee joint. The program includes components such as a warm-up, stretching, plyometrics, and sport-specific abilities (as shown in Table 1) [11].

During the PEP program, proper technique is emphasized in all exercises, and participants are encouraged to maintain correct posture during jumps, ensuring they move straight up and down, and reinforce proper landings to minimize the risk of injury [11].

The PEP program typically takes approximately 20 minutes to complete [11]. In this study, the intervention group incorporated the PEP program into their warm-up routine during three weekly training sessions for eight weeks.

Statistical Analysis

The data in the study are presented as mean±standard deviation (SD). Before the statistical analysis, the normality of the pre and post-values was checked using the Shapiro-Wilk normality test. The analysis of covariance (ANCOVA) was used to compare the differences between groups, and for comparing the differences within the groups, the paired-sample t-test was employed. The significance level for all statistical tests was set at $P<0.05$.

For the within-group comparisons, effect sizes were calculated using Cohen's d to measure the magnitude of the differences. Differences between groups in terms of age, height, weight, Body Mass Index (BMI), and years of practice were assessed using the independent-sample t-test. The data analysis was performed using SPSS version 24 (SPSS Inc., Chicago, IL, USA).

Results

The results presented in Table 2 indicate no significant differences between the intervention and control groups regarding age, height, weight, BMI, and years of practice (P>0.05). This finding suggests that the two groups were comparable in these demographic and anthropometric characteristics.

Furthermore, Table 2 also demonstrates no significant differences in the pre-test measurements of knee valgus angle, knee flexion angle, and LESS scores between the intervention and control groups (P>0.05). This finding suggests that both groups had similar baseline values for these outcome measures before the intervention.

Table 3 displays the results of the paired-sample t-test within each group. The intervention group showed a significant decrease in knee valgus angle (P=0.001), knee flexion angle (P=0.003), and LESS scores (P=0.001) after the 8-week intervention. On the other hand, the control group did not show significant changes in knee valgus angle (P=0.08) and knee flexion angle (P=0.06), but there was a significant improvement in LESS scores (P=0.001).

Finally, the results of covariance analysis in Table 4 revealed that after eight weeks, the intervention group exhibited a significant decrease in knee valgus angle (P=0.001), knee flexion angle (P=0.025), and LESS scores (P=0.001) compared to the control group.

Discussion

The present study aimed to investigate the effect of the PEP program on knee valgus angle, knee flexion

Table 1: Components of the Prevent Injury and Enhance Performance (PEP) program [11]

1. Warm-up
A. Jog line to line of a soccer field (cone to cone) (50m)
B. Shuttle run (side to side) (50m)
C. Backward running (50m)
2. Stretching
A. Calf stretch (2 reps)
B. Quadriceps stretch (2 reps)
C. Hamstring stretch (2 reps)
D. Inner thigh stretch (2 reps)
E. Hip flexor stretch (2 reps)
3. Strengthening
A. Walking lunges (2 sets × 20 m)
B. Nordic hamstring (3 sets × 10 reps)
C. Single toe-raises (30 reps on each side)
4. Plyometrics
A. Lateral hops over 5 to 15 cm cone (20 reps)
B. Forward/backward hops over 5 to 15 cm cone (20 reps)
C. Single leg hops over 5 to 15 cm cone (20 reps)
D. Vertical jumps with headers (20 reps)
E. Scissors jump (20 reps)
5. Agilities
A. Shuttle run with forward /backward running (40 m)
B. Diagonal runs (40 m)
C. Bounding run (50 m)

Table 2: Demographic characteristics of the intervention and control groups

Variable	Group	n	Mean±SD	T	P
Age (years)	Intervention	23	12.69±0.70	0.56	0.57
	Control	24	12.58±0.65		
Height (m)	Intervention	23	1.53±0.06	0.74	0.45
	Control	24	1.52±0.08		
Weight (kg)	Intervention	23	49.91±6.76	-0.63	0.53
	Control	24	51.25±7.73		
BMI (kg/m^2)	Intervention	23	21.21±3.22	-1.07	0.28
	Control	24	22.19±3.04		
Practice (years)	Intervention	23	4.08±1.04	-0.50	0.61
	Control	24	4.25±1.15		

Standard Deviation (SD); n-number; Body Mass Index (BMI)

Table 3: Results of paired-sample t-test showed the within-group differences

Variable	Group	Pre-test	Post-test	T	P	Percent	Cohen's d
		Mean±SD	Mean±SD			Change (%)	
Knee valgus angle (°)	Intervention	20.13±3.41	11.04±1.89	12.09	0.001*	45.15↓	3.29
	Control	19.54±3.27	18.75±2.60	1.70	0.08	4.04↓	0.26
Knee flexion angle (°)	Intervention	99.73±4.66	93.73±6.28	3.38	0.003*	6.01↓	1.08
	Control	101.12±5.82	98.04±6.12	1.95	0.06	3.04↓	0.51
LESS (score)	Intervention	9.17±1.43	5.73±1.35	32.49	0.001*	37.51↓	2.47
	Control	8.91±1.28	7.25±1.79	11.63	0.001*	18.63↓	1.06

Standard deviation (SD); Landing Error Scoring System (LESS); ↓-decrease; *-significant

Table 4: Results of ANCOVA analysis showed the differences between groups

Variables	Time	Group	Mean[a]	F	Partial Eta Squared	P
Knee valgus angle (°)	Post-test	Intervention	10.94	181.62	0.80	0.001*
	Post-test	Control	18.84			
Knee flexion angle (°)	Post-test	Intervention	93.74	5.39	0.10	0.025*
	Post-test	Control	98.03			
LESS (score)	Post-test	Intervention	5.59	100.59	0.69	0.001*
	Post-test	Control	7.38			

[a]Covariates appearing in the mean; Landing Error Scoring System (LESS); *Significant

angle, and LESS scores in young male soccer players with poor landing mechanics. The present study showed a significant reduction in knee valgus angle in the intervention group, which was not seen in the control group. The effectiveness of the exercises in the present study can be attributed to the simultaneous use of strength, plyometric, balance, stretching, and functional exercises, such as lunges, Nordic hamstring exercises, single toe-raises, vertical one and two-legged jumps, and multidirectional hops. These exercises improve muscle coordination, enhance knee control, and strengthen the core and hip muscles [18].

These exercises effectively strengthen the gluteal and hamstring muscles [19], leading to their earlier activation during landing maneuvers [19]. Increased gluteal activity helps limit knee valgus motion by controlling hip adduction and internal rotation, while hamstring activation, particularly on the medial side, may also restrict knee valgus motion by controlling frontal plane knee movement [19]. The findings from previous studies also support the results of the current research regarding the improvement of dynamic knee valgus [20, 21]. It has been demonstrated that a neuromuscular warm-up can significantly decrease the knee valgus angle in both the dominant (20.44 degrees) and non-dominant (15.43 degrees) legs of young male soccer players [21].

Additionally, it has been reported that a significant decrease in knee valgus angle was observed in soccer and basketball players after implementing a 6-week neuromuscular training program [20]. However, in contrast to our study results, Lindblom et al. [22] demonstrated no significant improvements in landing mechanics in young male soccer players after implementing an injury prevention program for eight weeks. The differences in results could be attributed to the low number of training sessions per week and low attendance in the latter study, limiting the opportunity for players to develop better neuromuscular adaptations [14].

Furthermore, the current study observed an increase in knee flexion angle in the intervention group compared to the control group. This improvement may be attributed to the plyometric training and Nordic hamstring exercises included in the PEP program, which can lead to earlier hamstring activation [19]. Proper timing of knee flexor muscle activation is crucial for achieving optimal knee flexion during landing, and the enhanced hamstring activation timing from the PEP program may have contributed to the improvement in knee flexion angle during landing in the intervention group [23].

Moreover, one of the key features of the PEP program is its emphasis on correct techniques during jumping and landing maneuvers, including maintaining a proper knee-over-toe position and ensuring flexed hip and knee positions. Providing feedback to participants about faulty movement patterns can be instrumental in promoting better landing strategies [18]. Feedback has been effective in improving men's landing techniques [24]. Consistent with the findings of our study, Chappell and Limpisvasti [20] also reported improvements in knee flexion during the landing phase of a drop-jump task following six weeks of neuromuscular training.

DiStefano et al. [25] also reported improvement in knee flexion after a 4-month training period. The increased knee flexion during the landing phase is essential for delaying energy absorption, thus reducing the vertical ground reaction and internal hip extension moment. These changes are protective mechanisms for the ACL [20, 25]. By landing with increased knee flexion, the risk of ligament dominance is minimized as the ligament's integrity is less likely to be compromised. Instead, energy absorption occurs through the lower extremity musculature, reducing the strain on the ACL and lowering the risk of ACL injuries [20, 25].

The current study supports the PEP program's positive impact on reducing LESS test scores, indicating an improvement in landing pattern errors. Neuromuscular training, as provided by the PEP program, enhances the activity of the gamma-efferent nerves in muscles, leading to increased sensitivity in the muscle spindles. This heightened sensitivity influences joint control, helping athletes to align their lower limbs during movements better [26]. The PEP program effectively improves neuromuscular control by focusing on decreasing landing forces and improving lower limb alignment from a valgus position to a neutral position [12]. The program's combination of strength, flexibility, and plyometric training contributes to joint awareness, balance, and neuromuscular properties [18]. Plyometric training, in particular, is crucial in enhancing athletic performance by promoting neuromuscular adaptations and correcting faulty jumping mechanics, ultimately leading to increased knee flexion angles and decreased knee valgus at landing [27].

Akbari et al. [28] demonstrated that an injury prevention program implemented for eight weeks resulted in improved LESS scores and landing patterns in elite youth soccer players. On the other hand, Donnelly et al. [29] reported that balance and technique training did not show positive effects on knee kinematics during sidestepping.

The distinguishing factor of the PEP program from the interventions used in the previous studies lies in its multifaceted approach. Unlike the other programs, the PEP program comprises a comprehensive set of components, including dynamic stretching, strength training, postural stability exercises, plyometric exercises, and balance training. Additionally, the PEP program incorporates specific cues for lower extremity and trunk alignment, which are integrated into the team warm-up routine. Traditional warm-up programs, on the other hand, lack these comprehensive components and alignment cues [18]. This multifaceted and integrated nature of the PEP program may have contributed to its effectiveness in inducing positive changes in the landing kinematics of young soccer players.

By improving landing kinematics, the PEP program potentially reduces the knee load experienced during soccer activities, decreasing the risk of ACL injuries [5].

Several limitations should be acknowledged in this study. Firstly, the study sample only consisted of young male soccer players, and therefore, the generalizability of the findings to female soccer players may be limited. Sex-based differences in landing biomechanics have been reported [22], and it is uncertain whether the effects of the PEP program on landing patterns would be similar for girls as they were for boys in this study. Secondly, the researchers could not follow up with tests over an extended duration, such as two or three months. Further research is needed to determine the persistence of the intervention programs over a longer period.

Conclusion

The findings of our study suggest that the PEP program can be considered appropriate, as it appears to be effective in reducing dynamic knee valgus angle, knee flexion angle, and LESS test scores compared to a traditional warm-up program. Furthermore, the program has the potential to influence risk factors for ACL injuries positively. Therefore, the PEP program meets the requirements for being capable of reducing knee injuries in young soccer players.

Conflict of Interest: None declared.

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