The Influence of In-Season Injury Prevention Training on Lower-Extremity Kinematics during Landing in Female Soccer Players

Christine D. Pollard, PhD, PT, Susan M. Sigward, PhD, ATC, PT, Susumu Ota, PT, Karen Langford, DPT, and Christopher M. Powers, PhD, PT

Objective: To examine the influence of in-season injury prevention training on hip and knee kinematics during a landing task.

Design: Longitudinal pre-post intervention study.

Setting: Testing sessions were conducted in a biomechanics research laboratory.

Participants: Eighteen female soccer players between the ages of 14 and 17 participated in this study. All subjects were healthy with no current complaints of lower extremity injury.

Interventions: Testing sessions were conducted prior to and following a season of soccer practice combined with injury prevention training.

Main Outcome Measurements: During each testing session three-dimensional kinematics were collected while each subject performed a drop landing task. Peak hip and knee joint angles were measured during the early deceleration phase of landing and compared between pre- and post-training using paired t-tests.

Results: Following a season of soccer practice combined with injury prevention training, females demonstrated significantly less hip internal rotation (7.1° vs. 1.9°; $P = 0.01$) and significantly greater hip abduction (−4.9° vs. −7.7°; $P = 0.02$). No differences in knee valgus or knee flexion angles were found post-season.

Conclusions: Female soccer players exhibited significant changes in hip kinematics during a landing task following in-season injury prevention training. Our results support the premise that a season of soccer practice combined with injury prevention training is effective in altering lower extremity motions that may play a role in predisposing females to ACL injury.

Key Words: ACL injury, hip kinematics, knee kinematics

(*Clin J Sport Med* 2006;16:223–227)

Received for publication July 2005; accepted February 2006.

From the Department of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles, CA.

Reprints: Christine Pollard, PhD, PT, University of Southern California, 1540 East Alcazar Street, CHP-155, Los Angeles, California 90089-9006 (e-mail: cpollard@usc.edu).

The incidence of anterior cruciate ligament (ACL) injury in females has been reported to be four to six times greater than males participating in the same sport.[1,2] Seventy percent of these injuries occur during an incident that involves no direct contact with another player or object, and often take place during a dynamic task such as landing or cutting as the athlete is decelerating and/or changing direction.[3–5] For example, Ferretti et al[6] examined 52 cases of serious knee ligament injuries in volleyball players and reported that 73% of these injuries occurred while landing from a jump.

It is thought that the disproportionate number of ACL injuries in female athletes is due to gender-related differences in performance of common athletic tasks. For example, studies evaluating lower-extremity kinematics during landing, cutting and running have shown that when compared to males, females exhibit greater hip adduction, hip internal rotation, knee valgus, and less knee flexion.[7–12] In vitro data suggests that the combination of knee valgus with the knee in relative extension (0–40°) places an increased load on the ACL.[13] In addition, hip internal rotation and adduction are thought to influence the position (ie, increased valgus) and the torque experienced at the knee.[2]

Recently, several injury prevention training programs have been designed in an attempt to reduce the number of non-contact ACL injuries. Studies investigating the effects of such programs in reducing ACL injury have been promising in that several authors have reported a decreased incidence of ACL injury following training.[14–17] For example, Hewett et al[15] reported that untrained female athletes had a 3.6-fold higher incidence of knee injury when compared to female athletes who participated in a six-week jump-training program. In addition, Mandelbaum et al[16] demonstrated a 74% reduction in ACL injuries among female high school soccer players who participated in an injury prevention program as part of their regular practice schedule.

Even though the literature supports the concept of injury prevention training to reduce ACL injuries, the underlying mechanism behind the success of such training remains unclear. For example, it is not known if in-season injury prevention training alters lower-extremity kinematics in a way that would be suggestive of decreased risk for ACL injury.

To date, there have been few studies examining the effect of injury prevention training on knee mechanics in female athletes. Hewett et al[18] reported no change in lower extremity kinematics in female athletes following participation in a 6-week jump-training program; however, this study was limited to the evaluation of the sagittal plane knee kinematics only. Additionally, since hip kinematics have an influence on the forces experienced at the knee,[19,20] and it has been suggested that gender differences in hip strength may partially explain the gender bias in ACL injury among female athletes,[21] it is important to evaluate the influence of training on hip kinematics during a dynamic lower extremity task.

The purpose of this study was to examine the influence of in-season injury prevention training on hip and knee kinematics during a landing task. It was hypothesized that following a season of soccer practice combined with injury prevention training, female athletes would demonstrate less hip adduction, hip internal rotation and knee valgus, as well as greater knee flexion during the deceleration phase of a landing task.

METHODS

Subjects

The coaches of three local club and high school soccer teams were contacted and agreed to incorporate injury prevention training into their regular season of practice. Subjects were excluded from the study if they reported any of the following: 1) history of previous ACL injury or repair; 2) previous injury that resulted in ligamentous laxity at the ankle, hip or knee; or 3) presence of any medical or neurological condition that would impair their ability to perform a landing task. Athletes on each team who met the inclusion criteria and agreed to participate in the study resulted in a convenience sample of 26 female soccer players, between the ages of 14 and 17. All participating subjects were healthy with no current complaints of lower extremity injury.

Instrumentation

Three-dimensional motion analysis was performed using a computer aided video (Vicon) motion analysis system (Oxford Metrics LTD. Oxford, England). Kinematic data were sampled at 120 Hz and recorded digitally on dual Pentium III 1GHz personal computer. Reflective markers (25 mm spheres) placed on specific bony landmarks (see below) were used to calculate motion of the hip, knee and ankle in the sagittal, frontal and transverse planes. Ground reaction forces where collected at a rate of 2,400 Hz using an AMTI force plate (Model#OR6-6-1, Newton, MA).

Procedures

Each subject participated in two testing sessions, one at the beginning of their soccer season and one following the soccer season. Testing took place at the Musculoskeletal Biomechanics Research Laboratory at the University of Southern California. All procedures were explained to each subject and informed consent was obtained as approved by the Institutional Review Board for the University of Southern California Health Sciences Campus.

Prior to testing, reflective markers were placed on the following anatomical landmarks: bilateral anterior superior iliac spines, posterior superior iliac spines, lateral epicondyles of the knee, lateral malleoli, calcaneus, and bases of the fifth metatarsal. The thigh and calf markers were mounted on 5 cm wands and secured on the thigh and shank with elastic bands. The foot markers were placed on the shoes. To control for the potential influence of varying footwear, subjects were fitted with same style of cross-training shoe (New Balance Inc., Boston, MA).

Each subject performed three trials of the drop landing task (Fig. 1). Subjects began this maneuver from a standing position on a 30 cm platform. They were instructed to step off the platform and land with their right foot on one force plate and their left foot on a neighboring force plate and then proceed to immediately jump as high as they could after landing. Subjects were not given any verbal cues on landing or jumping technique. Practice drop landings were allowed for the subjects to become familiar with the procedures and instrumentation.

Following the initial biomechanical assessment, subjects participated in their normal season of soccer

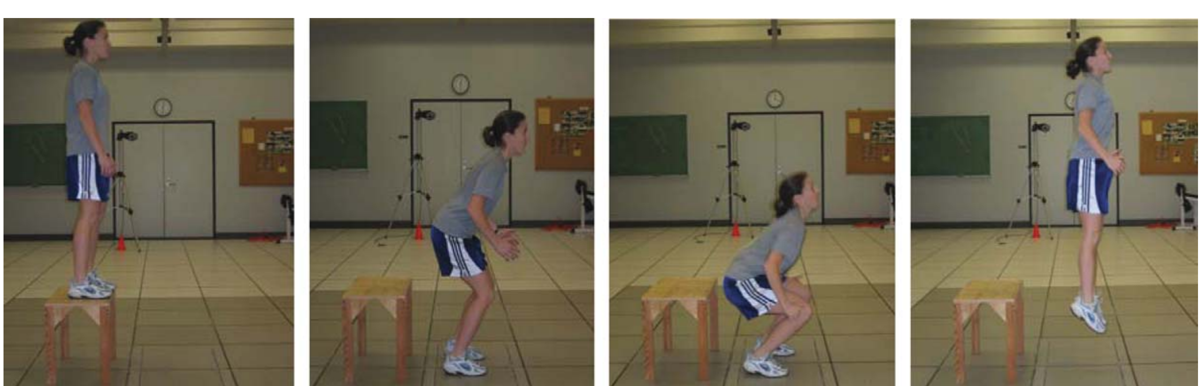

FIGURE 1. An example of the landing/jump task utilized in the current study.

TABLE 1. PEP Program Exercises

Exercise	Time
Warm-up	30–60 seconds each
Jog line to line	
Shuttle run	
Backward running	
Stretching	30 sec × 2 reps
Calf stretch	
Quadriceps stretch	
Figure four hamstring stretch	
Inner thigh stretch	
Hip flexor stretch	
Strengthening	30 sec × 2 reps
Walking lunges	
Russian hamstring	
Single toe raises	
Plyometrics	20 reps
Lateral hops over cone	
Forward/backward hops over cone	
Single leg hops over cone	
Vertical jumps with headers	
Scissors jump	
Agilities	
Shuttle run with forward/backward running	
Diagonal runs	
Bounding run	

which included competition as well as regular practice combined with the Prevent Injury and Enhance Performance (PEP) injury prevention training developed by the Santa Monica Orthopaedic and Sport Medicine Research Foundation (Santa Monica, CA).[16] This program was designed so that coaches can be educated, *via* written instructions and an instructional videotape, in how to implement the training program. Throughout the videotape, there is a strong emphasis on proper technique such as stressing soft landing and deep hip and knee flexion. The PEP training program was specifically designed to replace the traditional 20-minute soccer warm-up and a more detailed description of the program as well as it's effectiveness in reducing ACL injury can be found in previous literature.[15] Prior to the start of the season, each coach received written and videotaped instructions on how to integrate PEP training exercises into their regular practice (Table 1). All coaches agreed to include the training program in their practices which occurred two to three times a week, for their soccer season. Also, all coaches agreed to keep a record of subject compliance with the training sessions.

Failure to complete 80% of the regularly scheduled practices, as reported by the coach, resulted in the subject being dropped from the study. Following completion of the soccer season, all subjects who met our compliance criteria returned to the Musculoskeletal Biomechanics Research Laboratory where they underwent a post-season biomechanical assessment using the identical procedures as described above.

Data Analysis

Vicon Clinical Manager (VCM) software (Oxford Metrics LTD. Oxford, England) was used to quantify lower extremity motion in the sagittal, frontal and transverse planes. Kinematic data were filtered using a Woltering quintic spline filter with a predicted mean square error of 20 mm.

All data were normalized to 100% of the drop landing/jump cycle. This cycle was identified as the period from foot contact to foot toe-off, as determined by the force plate recordings. The right lower extremity was evaluated for all subjects as seventeen of the eighteen subjects were determined to be right leg-dominant. The dominant leg was defined as the leg in which the athlete preferred to use to kick a soccer ball.

For the purposes of this study, only the early deceleration phase of the drop landing was considered, as this has been suggested as the time in which the knee joint, including the ACL, undergoes the greatest forces in landing.[3] Early deceleration was defined as the first 20% of the drop landing/jump cycle.

Consistent with the proposed hypothesis, the dependent variables evaluated in this study included peak hip adduction, peak hip internal rotation, peak knee valgus and peak knee flexion during early deceleration. For each subject, all dependent variables represented the mean of three trials.

Statistical Analysis

Differences between pre-season and post-season kinematics were compared using paired *t*-tests. Statistical analyses were performed using SPSS statistical software (Chicago, IL). Significance levels where set at $P < 0.05$. Given the small sample size and pilot nature of this study, adjusting for multiple comparisons was deemed inappropriate.

RESULTS

During the course of the study, eight subjects were lost to attrition. Four subjects withdrew from the study following injury or illness not related to sport, two subjects did not return for post-season testing, and two subjects had faulty data in which their ASIS reflective markers were not visible. The remaining 18 subjects all completed at least 80% of their training sessions and their average age, height, and mass was 14.9 years, 163.0 cm and 58.3 kg respectively.

Table 2 presents a summary of the kinematic comparisons for the variables of interest. All kinematic

TABLE 2. Comparisons Peak Hip and Knee Angles Pre- and Post-Training (Mean (SD))

Variable	Pre-	Post-	Difference	*P*-value
Peak Angle (°)				
Hip adduction*	− 4.9 (4.0)	− 7.7 (4.7)	− 2.8	0.02
Hip internal rotation	7.1 (6.8)	1.9 (7.8)	− 5.2	0.01
Knee valgus†	1.6 (3.6)	− 0.1 (4.6)	− 1.7	0.15
Knee flexion	59.2 (8.0)	56.1 (12.1)	− 3.1	0.34

*Negative value indicates hip abducted position.
†Negative value indicates knee varus position.

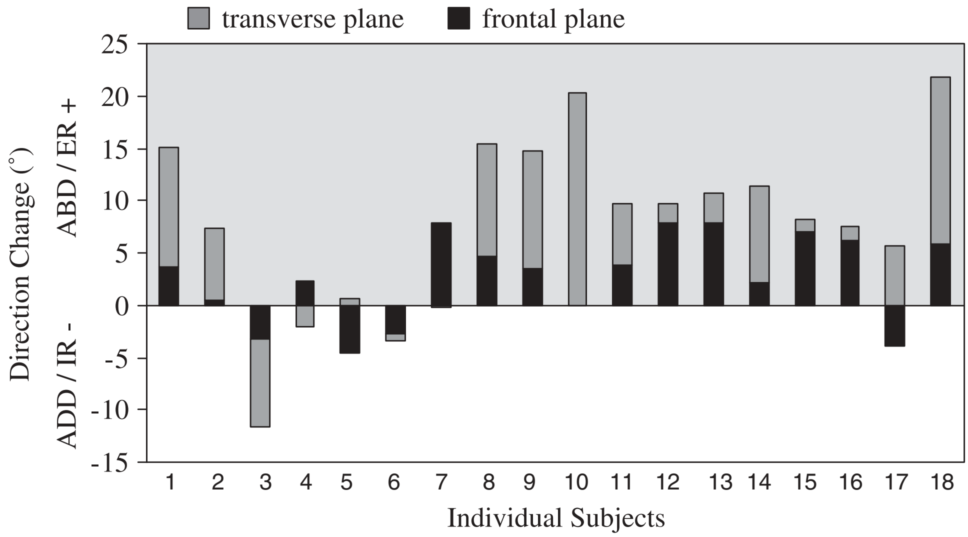

FIGURE 2. Individual subject changes in transverse and frontal plane hip motion during early deceleration of a landing task from pre- to post-season.

measurements were of the right lower extremity which was the dominant lower extremity for 17 of the 18 subjects. Following a season of regular soccer practice combined with injury prevention training, female soccer players demonstrated significantly less hip internal rotation (7.1° versus 1.9°; $P = 0.01$) and significantly greater hip abduction ($-4.9°$ versus $-7.7°$; $P = 0.02$). No differences in knee valgus or knee flexion angles were found post-season. In order to gain further understanding of the changes in hip joint frontal and transverse plane kinematics from pre- to post-season, the change in these motions among individuals was examined (Fig. 2). It was apparent that certain individuals experienced a greater change in motion in one plane versus the other.

DISCUSSION

It was hypothesized that following a season of soccer practice combined with injury prevention training, female soccer players would demonstrate less hip adduction, hip internal rotation and knee valgus, as well as greater knee flexion during the deceleration phase of a landing task. Our data partially supported our hypothesis in that female soccer players exhibited changes in lower extremity kinematics at the hip, but not at the knee, post-season. In particular, females exhibited decreased peak hip internal rotation and increased hip abduction during the early deceleration phase of landing. The current findings support the premise that a season of soccer practice combined with injury prevention training is effective in altering lower extremity kinematics.

Previous work has identified gender differences in hip rotation during dynamic activities. More specifically, Lephart et al[9] reported that female athletes, comprised of soccer, volleyball and basketball players, exhibited greater peak hip internal rotation than did their male counterparts when performing a single-leg landing from a jump. Subsequently, Ferber et al[7] reported that female distance runners exhibited greater peak hip internal rotation than did their male counterparts during the stance phase of running. This kinematic pattern of increased hip internal rotation is consistent with the rotatory mechanism observed when subjectively examining videos of non-contact ACL injuries.[3] The fact that hip internal rotation decreased following training suggests that this variable could be a factor underlying the prevalence of ACL injury among female athletes.

Although female soccer players did not exhibit a hip adducted position during the early deceleration phase of the landing task, they did demonstrate significantly greater peak hip abduction post-season. Investigators that have examined gender differences in hip adduction have found that females demonstrate greater peak hip adduction during running[7] and relatively less hip abduction during cutting[12] when compared to males. These authors have suggested that females may be at greater risk of knee injury due to this tendency towards hip adduction during dynamic tasks. Their rationale is based on the premise that increased hip adduction can contribute to increased knee valgus which has been identified in the literature as a motion that loads the ACL.[13] Therefore, in the current investigation, the female soccer player's tendency to move away from a hip adducted position from pre- to post-season could be interpreted as a beneficial effect of training. However, care must be taken in overstating this finding due to the small observed difference (~ 3 degrees on average).

While we had found that this group of females exhibited less hip internal rotation and relatively more hip abduction following training, we were interested in how these changes were distributed among individuals. After plotting the hip transverse and frontal plane change among individuals, it became evident that the majority of subjects either experienced a change in motion toward hip external rotation, hip abduction or a combination of both (Fig. 2). Interestingly, certain individuals appeared to experience a greater change in motion in one plane, such as transverse, versus the other. These individual data suggest that not all subjects responded the same. Rather, it may be the case that while soccer practice combined with injury prevention training influenced hip motion in the transverse and frontal planes, individuals may have more readily responded to change in the plane in which they exhibited a pre-existing at-risk pattern.

Despite changes in hip kinematics, our subjects did not demonstrate a change in peak knee valgus and peak knee flexion. Even though several studies examining gender differences in lower extremity kinematics have reported that female athletes exhibit less knee flexion[8,9] and greater knee valgus[6,9,10] during dynamic tasks, we suspect that these variables did not change due to the simplicity of the landing task. While the task utilized for the current study consisted of a double limb drop landing, a more challenging single limb drop landing may have resulted in more apparent changes in knee kinematics from pre- to post-season. More specifically, we suspect that the decreased peak hip internal rotation and increased hip abduction observed during the double limb drop landing may contribute to decreased knee valgus during a more demanding loading task.

A limitation of the current study was the small sample size which may have limited our ability to detect significant differences in knee kinematic variables. Regarding our statistical analysis, we recognize that the lack of multi-variable analysis has potential confounding effects. 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. Finally, even though we were limited by our reliance on the coaches to accurately report subject compliance, a change in lower extremity kinematics was found.

In conclusion, female soccer players exhibited significantly less peak hip internal rotation and significantly greater peak hip abduction during a landing task following a season of soccer practice combined with injury prevention training. Therefore, it may be the case that in-season training, which affects certain lower extremity patterns, could in turn protect the knee during actual game-like conditions.

REFERENCES

1. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *Am J Sports Med*. 1995;23:694–701.
2. Griffin LY, Agel J, Albohm MJ, et al. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. *J Am Acad Orthop Surg*. 2000;8:141–150.
3. Boden B, Dean G, Feagin J, et al. Mechanisms of Anterior Cruciate Ligament Injury. *Orthopedics*. 2000;23:573–578.
4. McNair PJ, Marshall RN, Matheson JA. Important features associated with acute anterior cruciate ligament injury. *N Z Med J*. 1990;103:537–539.
5. Myklebust G, Maehlum S, Holm I, et al. A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball. *Scand J Med Sci Sports*. 1998;8:149–153.
6. Ferretti A, Papandrea P, Conteduca F, et al. Knee ligament injuries in volleyball players. *Am J Sports Med*. 1992;20:203–207.
7. Ferber R, Davis IM, Williams DS. Gender differences in lower extremity mechanics during running. *Clin Biomech*. 2003;18: 350–357.
8. Ford KR, Myer GD, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. *Med Sci Sports Exerc*. 2003;35:1745–1750.
9. Lephart SM, Ferris CM, Riemann BL, et al. Gender differences in strength and lower extremity kinematics during landing. *Clin Orthop Rel Res*. 2002;401:162–169.
10. Malinzak RA, Colby SM, Kirkendal DT, et al. A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clin Biomech*. 2001;16:438–445.
11. McLean SG, Neal RJ, Myers PT, et al. Knee joint kinematics during the sidestep cutting maneuver: potential for injury in women. *Med Sci Sports Exerc*. 1999;31:959–968.
12. Pollard CD, Davis IM, Hamill J. Influence of gender on hip and knee mechanics during a randomly cued cutting maneuver. *Clin Biomech*. 2004;19:1022–1031.
13. Markolf KL, Burchfield DM, Shapiro MM, et al. Combined knee loading states that generate high anterior cruciate ligament forces. *J Orthop Res*. 1995;13:930–935.
14. Carrafa A, Cerulli M, Projetti M, et al. Prevention of anterior cruciate ligament injuries in soccer. *Knee Surg Sports Traumatol Arthrosc*. 1996;4:19–21.
15. Hewett TE, Riccobene JV, Lindenfeld TN. The effect of neuromuscular training on the incidence of knee injury in female athletes: A prospective study. *Am J Sports Med*. 1999;24:699–706.
16. Mandelbaum BR, Silvers HJ, Watanabe DS, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes. *Am J Sports Med*. 2005;33:1003–1010.
17. Myklebust G, Engebretsen L, Braekken IH, et al. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med*. 2003;13:71–78.
18. Hewett TE, Stroupe AL, Nance TA, et al. Plyometric training in female athletes. *Am J Sports Med*. 1996;24:765–773.
19. Lee TQ, Anzel SH, Bennett KA, et al. The influence of fixed rotational deformities of the femur on the patellofemoral contact pressures in human cadaver knees. *Clin Orthop*. 1994;69–74.
20. Powers CM, Ward SR, Fredericson M, et al. Patellar kinematics during weight-bearing and non-weight-bearing movements in persons with patellar subluxation. *J Orthop Sports Phys Ther*. 2003; 33:639–646.
21. Leetun DT, Ireland ML, Wilson JD, et al. Core stability measures as risk factors for lower extremity injury in athletes. *Med Sci Sports Exerc*. 2004;36:926–934.