Gender Differences in the Kinematics of Unanticipated Cutting in Young Athletes

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ABSTRACT

FORD, K. R., G. D. MYER, H. E. TOMS, and T. E. HEWETT. Gender Differences in the Kinematics of Unanticipated Cutting in Young Athletes. *Med. Sci. Sports Exerc.*, Vol. 37, No. 1, pp. 124–129, 2005. **Purpose:** Anterior cruciate ligament (ACL) injuries occur at a greater rate in adolescent females compared with males who participate in the same pivoting and jumping sports. The purpose of this study was to compare knee and ankle joint angles between males and females during an unanticipated cutting maneuver. The hypotheses were that female athletes would display increased knee abduction, increased ankle eversion and decreased knee flexion during the unanticipated cutting maneuver compared with males. **Methods:** Fifty-four male and 72 adolescent female middle and high school basketball players volunteered to participate in this study. Knee and ankle kinematics were calculated using three-dimensional motion analysis during a jump-stop unanticipated cut (JSUC) maneuver. **Results:** Females exhibited greater knee abduction (valgus) angles compared with males. Gender differences were also found in maximum ankle eversion and maximum inversion during stance phase. No differences were found in knee flexion angles at initial contact or maximum. **Conclusion:** Gender differences in knee and ankle kinematics in the frontal plane during cutting may help explain the gender differences in ACL injury rates. Implementation of dynamic neuromuscular training in young athletes with a focus on frontal plane motion may help prevent ACL injuries and their long-term debilitating effects. **Key Words:** ACL INJURY, NEUROMUSCULAR CONTROL, KNEE INJURY PREVENTION, ADOLESCENT FEMALE ATHLETE, JUMP STOP LANDING, BIOMECHANICS

Adolescent females who participate in pivoting and jumping sports sustain anterior cruciate ligament (ACL) injuries at a 4–6 times greater rate than adolescent males participating in the same sports (13). In combination with the higher female rate of ACL injuries there has been a dramatic increase in participation rates since the inception of Title IX in 1972. This has lead to considerable increases in the number of ACL injuries in female athletes over the last three decades

The factors underlying the injury rate differences between genders have previously been categorized into several general theories: anatomical, hormonal, and biomechanical as well as other extrinsic factors. Anatomical risk factors that have been proposed include increased Q-angle, narrower femoral notch, and increased hypermobility or laxity in female athletes. These anatomical variables, however, have not been directly correlated with an increased risk of noncontact ACL injury (10). Cyclic changes in female hormones may be possible contributors to the increased injury rates in female athletes (11). This may result in decreased ligament strength or altered muscle strength in female athletes. The experimental findings regarding the influence of hormones on injury risk are limited and remain controversial (10). Another potential mechanism is biomechanical or neuromuscular differences between genders. Neuromuscular control specifically relates to the activation of the dynamic restraints surrounding a joint in response to sensory stimuli (10,12). Neuromuscular mechanisms may prove to play the largest role in the gender differences found in ACL injuries (10). This is supported by evidence that injury prevention programs that focused on neuromuscular control of the lower extremity have been shown to reduce noncontact ACL injuries in female athletes (13,23).

Neuromuscular control of the lower extremity effects multiple joints and muscles. Kinematic differences at the ankle, knee, hip, and trunk may be responsible for gender differences in ACL injury rates (10). Variations in any of these lower extremity joint angles have been shown to influence joint forces, moments, and muscular activation patterns. Nyland et al. (27) showed that differences in frontal plane lower extremity alignment affected the postural control strategy used during single-limb balance at 20° knee flexion. Athletes with genu valgus or genu varus displayed a more posterior directed center of pressure than those with neutral alignment (27).

Quick change of direction is often cited as the injury mechanism during noncontact ACL ruptures (7,21). In team handball, for example, approximately 80% of ACL injuries occurred during a plant and cut movement or while landing

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from a jump (24). High-risk movements (i.e., cutting, rotating, and landing) occur as often as 70% of the time during the active part of a basketball game (29). These movements are typically not planned or anticipated so the athlete must react during the game to a ball or defensive player.

Postural adjustments and reflex responses may be altered due to the anticipation of a sports movement (4). Besier et al. (5) examined a high-risk maneuver at two different cutting angles under both preplanned and unanticipated conditions; however, no gender comparisons were made in this study. Kinematic and kinetic analysis of unanticipated cutting maneuvers may closely simulate the motion and torque the lower extremity experiences during sports play as there is limited time for an athlete to make postural adjustments (5). The use of unanticipated elements during athletic maneuvers may better mimic those which occur in high-risk sports than planned maneuvers and may identify possible gender-related ACL injury mechanisms.

Kinematic analysis of pivoting and landing maneuvers performed by young female athletes participating in high school and middle school sports may be important for the elucidation of the mechanism of increased ACL injury risk. Though similar numbers of ligament sprains occur in females and males before adolescence, females have higher rates immediately following their growth spurt and into maturity (30). Shea et al. (28) reported an analysis of insurance claims in 6 million youth soccer players. Beginning at age 12, a significantly greater number of ACL injury claims (ratio to overall claims) were reported in females compared with males (28).

The athletes included in the current study were middle and high school age (12–18 yr old), which includes athletes ranging in age from the beginning or divergence in ACL injuries between genders and through the peak number of ACL injuries in females (28). With approximately 30 million children participating in organized sports in the United States alone (1), focus on the identification of mechanisms of injury for this population is warranted. The purpose of this study was to compare knee and ankle joint angles between males and females during an unanticipated cutting maneuver. The first hypothesis of the current study was that female athletes would display increased knee abduction (valgus) during the cutting maneuver compared with males. The second hypothesis was that ankle eversion angles would be greater in female athletes. The third hypothesis was that females would perform the cutting maneuver with decreased knee flexion compared with males. The final hypothesis tested was that gender differences would exist during the static ready position before the cut in ankle and knee kinematics.

METHODS

A total of 126 basketball players were included in the study from area middle and high schools: 54 male athletes (25 middle school, 29 high school) and 72 female athletes (37 middle school, 35 high school) were tested in the 2 wk before their upcoming competitive season once the team rosters had been selected (Table 1). Informed written consent, approved by the Cincinnati Children's Hospital Medical Center Institutional Review Board, was obtained from the parent or guardian of each subject.

TABLE 1. Subject demographics (mean ± SD).

	Male	Female
	N = 54	N = 72
Height (cm)	171.0 ± 13.9	163.8 ± 8.3
Weight (kg)	61.8 ± 14.7	56.3 ± 12.5
BMI	20.9 ± 2.7	20.8 ± 3.3
Age (yr)	14.5 ± 2.2	14.3 ± 1.9

Experimental design. After informed consent was obtained, height, weight, BMI, and dominant leg were assessed. The operational definition of dominant leg was determined for each subject by asking which leg they would use to kick a ball with as far as possible (9). Each subject was instrumented with 23 retroreflective markers (9). The motion analysis system consisted of eight digital cameras (Eagle cameras, Motion Analysis Corporation) and two force platforms (AMTI) that were time synchronized and sampled at 240 Hz and 1200 Hz, respectively. Data were collected with EvaRT (Version 3.21, Motion Analysis Corporation) and imported into KinTrak (Version 6.2, Motion Analysis Corporation) for data reduction and analysis. Before each data collection session, the motion analysis system was calibrated to manufacturer recommendations.

A static trial was collected to align the joint coordinate system to the laboratory. The subject was instructed to stand still and was aligned as closely with the laboratory coordinate system as possible. This measurement was used as each subject's neutral (zero) alignment; subsequent kinematic measures were in relation to this position. Each subject was shown the jump-stop, unanticipated cut maneuver (JSUC) and allowed to practice the maneuver first without observing the visual unanticipated direction cue. This maneuver was selected in order to examine a common athletic and potentially high ACL injury risk movement that occurs in basketball, as well as other sports (7). Incorporation of unanticipated elements into testing protocols may better mimic the demands placed on the lower extremity during sport (4). Each subject was positioned in an athletic ready position to react to a randomized unanticipated direction cue. The ready position was established before cutting trials (Fig. 1). The knee flexion-extension angle was collected (via the motion analysis system) as each subject slowly flexed his or her knees. When the subject reached approximately 45° (± 5°) of knee flexion on the right leg they were instructed to hold that position for 4 s. The subject was instructed to reposition his or her knees to the same flexed position before the start of each JSUC trial. A custom computer program (KRF) simulated a stoplight on a monitor (red, yellow, then green) and was used to cue the subject when to initiate the forward jump (0.4 m). After the green (go) light (0.3 s), an arrow directing the subject which way to cut was displayed on the same computer monitor. The subject was instructed to perform a sidestep cut at a 45° and run past a marker 2.5 m away. For example, when cutting to

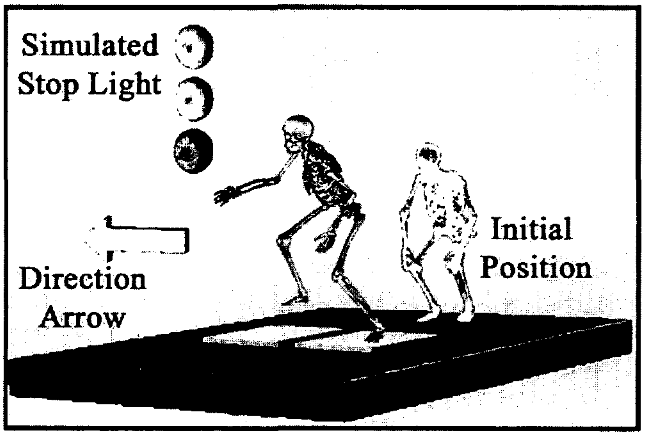

FIGURE 1—Illustration of jump-stop unanticipated cut (JSUC) maneuver.

TABLE 2. Knee and ankle kinematics during the JSUC (mean ± SEM).

	Side	Male	Female
Knee Angle (°)			
Flexion IC	Dominant	30.4 ± 1.4	30.0 ± 1.1
	Nondominant	31.0 ± 1.2	31.0 ± 1.0
Flexion maximum	Dominant	59.3 ± 1.2	59.8 ± 1.0
	Nondominant	57.5 ± 1.0	60.8 ± 0.9
Abduction IC	Dominant	−1.2 ± 1.1*	−3.7 ± 0.9*
	Nondominant	−1.6 ± 0.8*	−4.0 ± 0.8*
Abduction maximum	Dominant	−16.8 ± 2.1	−19.1 ± 1.4
	Nondominant	−14.5 ± 1.6	−18.4 ± 1.5
Adduction maximum	Dominant	10.1 ± 0.8	9.0 ± 1.5
	Nondominant	10.4 ± 1.4	9.6 ± 1.5
Ankle Angle (°)			
Eversion IC	Dominant	2.2 ± 1.0	2.3 ± 0.8
	Nondominant	2.8 ± 0.8	2.5 ± 0.6
Eversion maximum	Dominant	−15.0 ± 1.4*	−19.7 ± 1.0*
	Nondominant	−14.4 ± 1.1*	−19.9 ± 0.9*
Inversion maximum	Dominant	11.3 ± 1.0*	8.2 ± 0.7*
	Nondominant	10.1 ± 0.8*	7.5 ± 0.6*

* Significant gender effect $P < 0.05$; mean ± SEM.

the right the subject pushed off with her left limb and lead with her right. Trials were excluded if the subject performed a crossover cut or if the entire foot did not land on the force plate. The direction of the arrow was randomized over six trials (three each direction) providing the unanticipated element to the maneuver. The two force platforms were embedded into the floor and positioned 8 cm apart so that each foot would contact a different platform during the maneuver.

Data analysis. The three-dimensional Cartesian marker trajectories from each trial were estimated using the DLT method and filtered through a low-pass Butterworth digital filter as previously described (9). Ankle and knee joint angles for the dominant and nondominant leg were calculated from an embedded joint coordinate system. Ankle eversion-inversion angles were reported as 0° representing the subject's measured static position with positive numbers representing inversion. Knee flexion-extension angle was reported as 0° representing full extension with positive numbers representing flexion. Knee abduction-adduction angle was reported as 0° representing the subject's static standing position positive numbers representing adduction and negative numbers representing abduction (distal tibia moving away from midline) orientation. Vertical ground reaction force was used to identify the time at initial contact with the ground (IC) and at toe off from the cut (TO). Angle measurements at IC and the maximum angle during stance (IC − TO) were recorded. Angle measurements immediately before the start of cut were also obtained for each subject.

Reliability measurements. The within session test-retest reliability of all measures was evaluated by calculating intraclass correlation coefficients (ICC[3,k]) from three trials of cutting data. The knee abduction-adduction angle measurements showed good to excellent within session reliability (initial contact R = 0.93, maximum abduction R = 0.94 and maximum adduction R = 0.95). Ankle eversion-inversion angles showed similar reliability during the JSUC maneuver (initial contact R = 0.88, maximum eversion R = 0.95, and maximum inversion R = 0.88).

Statistical analysis. Statistical means and standard errors of the mean for each variable were calculated for each subject. A two-way mixed design ANOVA was used to determine the effect of gender (male and female) and side (dominant and nondominant) on each dependent variable ($P < 0.05$). A Pearson correlation coefficient was measured to compare height and weight with kinematic variables. Statistical analyses were conducted in SPSS (SPSS for Windows, Release 10.0.7).

RESULTS

A summary of knee and ankle kinematics is presented in Table 2. Average knee joint angles (abduction-adduction) during the stance phase of the JSUC maneuver are shown in Figure 2 for the male and female groups. A group main effect for gender was found for knee abduction angle at initial contact ($F(1,124) = 4.6$, $P = 0.033$). Females had greater knee abduction at initial contact compared with male athletes (Fig. 3). A main effect of gender was not found for

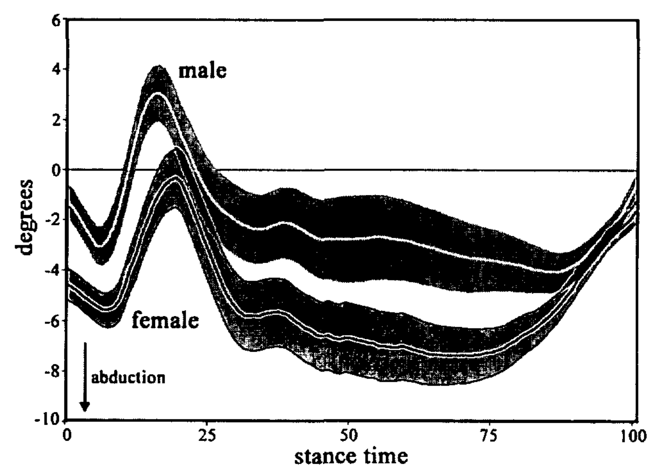

FIGURE 2—Average knee abduction-adduction angle normalized to stance phase during the JSUC for male (white line) and female (black line) subjects. Standard error of the mean (±) is displayed in a gray band for each group. Angle measurements for each subject were averaged across 101 data points (stance phase) for visualization.

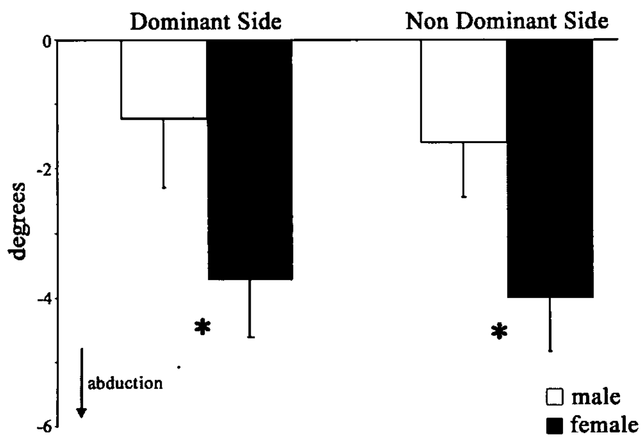

FIGURE 3—Knee abduction angle at initial contact in male and female athletes; * significant differences, $P < 0.05$.

maximum abduction angle or maximum adduction angle during stance phase of the cutting maneuver ($F(1,124) = 2.7$, $P = 0.106$; $F(1,124) = 1.1$, $P = 0.303$, respectively).

Ankle eversion-inversion angle at initial contact and maximum eversion and maximum inversion angles during stance are displayed in Figure 4. A significant effect for gender was found for both maximum ankle eversion angle ($F(1,124) = 14.2$, $P < 0.001$) and for maximum ankle inversion angle ($F(1,124) = 8.3$, $P = 0.005$). Female athletes had increased maximum ankle eversion angles and decreased maximum ankle inversion angles compared with males. A main effect of gender was not found at initial contact for ankle eversion angle ($F(1,124) = 0.01$, $P = 0.927$).

There were no main gender effects for knee flexion at initial contact or at maximum flexion angle during the JSUC ($F(1,124) = 0.02$, $P = 0.902$; $F(1,124) = 2.0$, $P = 0.161$, respectively). A main effect of side (side to side differences) in knee and ankle angle measurements was not found.

Each athlete before the start of the data collection session was shown an approximate 45° knee angle position and asked to reproduce that angle (ready position) while awaiting the visual cue to initiate the JSUC. There was no gender effect on the starting knee flexion-extension angle position before the JSUC maneuver ($F(1,122) = 2.4$, $P = 0.125$). The knee flexion angle in the starting position in females was 45 ± 1° (dominant) and 46 ± 1° (nondominant), whereas males started at 42 ± 1° (dominant) and 44 ± 1° (nondominant). Knee abduction angle was significantly different between genders. The females at the start position demonstrated an increased knee abduction angle compared with males (female −8 ± 1° dominant and −8 ± 1° nondominant; male −4 ± 1° dominant and −3 ± 1° nondominant; $F(1,122) = 9.0$, $P = 0.003$). There was no main gender effect in ankle inversion-eversion angle during the ready position (female −13 ± 1° dominant and −12 ± 1° nondominant; male −11 ± 1° dominant and −11 ± 1° nondominant; $F(1,122) = 1.8$, $P = 0.189$).

Because the two groups differed in height and weight ($P < 0.05$) we analyzed the potential effect of these two parameters. There was no correlation between knee abduction angle and height (initial contact $R = -0.14$, $P = 0.13$; maximum abduction $R = -0.01$, $P = 0.93$) or weight (initial contact $R = -0.07$, $P = 0.47$; maximum abduction $R = -0.02$, $P = 0.81$).

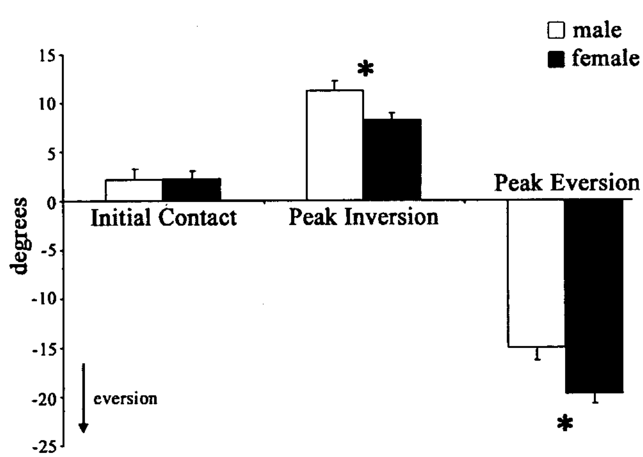

FIGURE 4—Dominant-side ankle inversion-eversion angle measurements in male and female athletes; * significant differences, $P < 0.05$.

DISCUSSION

The purpose of this study was to compare knee and ankle joint angles between males and females during an unanticipated cutting maneuver. Identification of gender differences in adolescent athletes may elucidate mechanisms of increased incidence of ACL injuries beginning at puberty and continuing through maturation. The current findings support our first hypothesis, that females would display increased knee abduction angles during the JSUC compared with males. Females had greater knee abduction angles at initial contact compared with males. Although differences were not found in maximum knee abduction angle the trend toward increased knee abduction (lower extremity valgus) may relate to ligament dominance and may be a potential risk factor for ACL injury (12). Ligament dominance occurs when an athlete allows the knee ligaments, rather than the lower extremity musculature, to absorb a significant portion of the ground reaction force during sports maneuvers. It is the opposite of muscle dominant. Andrews and Axe (2) first introduced the concept of cruciate dominance in their classical analysis of knee ligament instability. Hewett and colleagues (12) expanded the concept with their description of ligament dominance during sports activities. Ligament dominance, visually evidenced by increased medial knee motion during sports maneuvers, can result in high valgus knee moments and high ground reaction forces. Typically during cutting or landing, the female athlete allows the ground reaction force to control the direction of motion of the lower extremity joints. Therefore, the ligament takes up a disproportionate amount of force. Female athletes that demonstrate ligament dominance may show excessive dynamic valgus (increased hip adduction, knee abduction, and ankle eversion). Although the maximum knee abduction angle during the cut was not significantly different between genders, it did appear that females demonstrated greater knee abduction angles compared with males during the maneuver (Fig. 2).

Greater dynamic knee abduction (valgus) in female athletes has been previously shown in other types of athletic maneuvers. Female high school basketball athletes were shown to have greater knee valgus angles and motion during a box drop vertical jump (9). Malinzak et al. (19) examined collegiate recreational athletes and found greater valgus angles during running, sidestep cuts, and crossover cuts in females. McLean et al. (20) also found that female athletes (mean age 19 yr) had increased maximum knee valgus angles during sidestep cuts, but showed no differences during running compared with males. We utilized a different population of adolescent athletes compared with published studies to attempt to delineate potential mechanisms related to the when the difference in ACL injury rates occur between male and female athletes. The difference in ACL injuries between genders appears to occur around age 12, whereas the maximum number of ACL injuries in females seem to occur at age 16 (28).

Female athletes had a significantly greater knee abduction angle when readying themselves to execute the maneuver compared with males. This partially supports our fourth hypothesis, that differences would exist during the ready position before the cutting maneuver. However, there was no difference in knee flexion angle between genders. The differences in knee angle measurements were not due to standing alignment as these were adjusted to each subject's standing anatomic alignment. Gender differences in knee abduction angle during athletic maneuvers as well as during a ready position suggest altered muscular control of the lower extremity and likely reflects gender differences in contraction patterns of the adductors and abductors of the knee and hip. Females that employ muscular contraction patterns that place their knee into valgus during quasi-static positions are likely increasing knee loads. Inappropriate muscular contraction patterns may also magnify knee joint torques during dynamic maneuvers. Attention to both dynamic and ready positions should be incorporated when evaluating athletes, as they seem to be related and potentially linked to ACL injury risk.

The second hypothesis, that female athletes would have greater maximum ankle eversion than males during the stance phase of the JSUC, was also supported by the study findings. Increased ankle eversion may be a potential factor related to the gender differences found in ACL injury rates. Increased valgus knee stress and a preloading effect on the ACL may result from excessive eversion or pronation (18,26). This is may be due in part to a coupling of foot eversion and internal tibial rotation (3,22,26). A near linear correlation may be present between foot eversion and tibial internal rotation (3). Loudon et al. (18) found that excessive subtalar joint pronation was a significant factor in ACL injured patients compared with controls. A dangerous valgus position before and during cutting may be amplified when combined with ankle eversion and tibial rotation later in stance phase.

There were no gender differences found in knee flexion angle at initial contact or at maximum knee flexion during the stance phase of the JSUC. Published findings on the effects of gender on knee flexion angle are quite variable. For example, during a sidestep maneuver females have been shown to have less knee flexion during stance phase compared with males (19), whereas no gender differences were found in another report performing the same maneuver (20). During a drop landing from different heights, Huston et al. (15) showed significantly less knee flexion at initial contact from two different heights (40 cm and 60 cm), but not at the lowest height (20 cm). Conversely, Fagenbaum and Darling (8) found that female athletes landed with significantly greater knee flexion angles compared with males. They suggested that the unexpected results were possibly due to the controlled laboratory conditions during the anticipated movements (8). We found no difference in knee flexion angles in our study population who were instructed to react to the unanticipated visual cue. This method was selected to attempt to replicate a possible game situation in the laboratory.

This study is novel in that kinematic gender differences at the knee are reported during an unanticipated cutting maneuver. The addition of an unanticipated element to the athletic maneuver may better simulate game situations than previous studies and may better identify possible ACL injury mechanisms. Besier et al. (5) examined a sidestep cut at two different angles under both preplanned and unanticipated conditions; however, no gender comparisons were made. In male athletes, they found increased varus-valgus and internal-external knee moments during unanticipated movements and suggested that there may be increased potential for noncontact knee injuries during unanticipated sport movements. Lower-extremity muscle activation during cutting may be different between preplanned and unanticipated conditions (4). The unanticipated sidestep condition was reported to increase muscle activation in males 10–25%, with the greatest increase before initial contact (4).

Neuromuscular training conducted during adolescence increases neuromuscular function related to improved movement biomechanics that may lead to reduction of ACL knee injuries (13,14). Unanticipated cutting movements may prove to be an important component of neuromuscular training. Neuromuscular training protocols that do not incorporate cutting maneuvers may not provide similar levels of external varus-valgus or rotational loads that are seen during sport specific cutting maneuvers (17). Neuromuscular training that incorporates safe levels of varus-valgus stress may induce more "muscle-dominant" neuromuscular adaptations (16), whereby enhancing muscle recruitment and reaction times may provide greater and earlier muscle precontraction that would allow appropriate kinematic adjustments to reduce ACL loads (6,25).

Before instruction of unanticipated cutting drills, athletes may find it easier to work on proper knee positioning in a static athletic ready position. The athletic position is a functionally stable position with the knees comfortably flexed, shoulders back, eyes up, feet approximately shoulder-width apart, and the body mass balanced over the balls of the feet. The knees should be over the balls of the feet with limited knee valgus and ankle eversion and with the chest over the knees (14). Adding directional cues to the unanticipated component of training can be as simple as the trainer pointing out a direction or as sports-specific as using partner mimic or ball retrieval drills. Training the athlete to employ safe cutting techniques in unanticipated sport situations may instill technique adaptations that will more readily transfer onto the field of play. Prevention of female ACL injury from five times to equal the rate of males would allow tens of thousands of young females to continue the health benefits of sports.

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