The Drop-Jump Screening Test

Difference in Lower Limb Control By Gender and Effect of Neuromuscular Training in Female Athletes

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Background: A valgus lower limb alignment has been noted during noncontact anterior cruciate ligament injuries. A video drop-jump test can indicate an athlete's ability to control lower limb axial alignment in the coronal plane.

Hypotheses: Female athletes have decreased knee separation distances on landing and acceleration; male athletes have a neutrally aligned lower limb position. A neuromuscular training program will significantly increase knee separation distance in female athletes.

Study Design: Cohort study; Level of evidence, 2.

Methods: The authors tested 325 female and 130 male athletes aged 11 to 19 years. The distance between the hips, knees, and ankles was measured during a drop-jump test. The separation distance between the knees and ankles was normalized by the hip separation distance. A neuromuscular training program (Sportsmetrics) was completed by 62 female athletes, and their jump-landing characteristics were reexamined.

Results: A marked decrease in knee separation distance was found on takeoff in 80% of female athletes and in 72% of male athletes. There was no difference between male and female athletes in the normalized knee and ankle separation distance during the landing and takeoff phases. The knee separation distance on landing was 23 ± 9 cm in the female athletes and 22 ± 8 cm in the male athletes. The normalized knee separation distance was 51% ± 19% in the female athletes and 51% ± 15% in the male athletes. After training, statistically significant increases were found in the female athletes in the knee separation distance on landing (29 ± 8 cm, $P < .0001$) and in the normalized knee separation distance (68% ± 18%, $P < .0001$). The trained female athletes had significantly greater knee separation distance and normalized knee separation distance than did the males ($P < .0001$).

Conclusions: The majority of untrained female and male athletes demonstrated a valgus alignment appearance on the video test. After neuromuscular training, female athletes had improved knee separation distances and a more neutral lower limb alignment on landing and takeoff.

Keywords: video drop-jump test; lower limb alignment; neuromuscular training

The increased risk of noncontact ACL injuries in female athletes compared with that in male athletes has received a significant amount of attention in the past several years. Investigators have focused on various risk factors leading to these injuries[9] and on neuromuscular training programs designed to decrease the disparity between genders regarding ACL injury rates.[11,12,20] Studies have demonstrated that a valgus lower limb alignment is commonly seen during noncontact ACL injuries, which occurs when an athlete either lands from a jump or attempts to accelerate into a jump.[2,7,8] Previous investigations have examined differences between genders in knee flexion angles[13] and ground-reaction forces on the lower extremity on landing.[12,19,23,24,26]

Berns et al reported that in a cadaveric model, a valgus torque combined with an anterior tibial force resulted in a statistically significant larger strain in the ACL than with an anterior force alone ($P < .0001$).[1] The authors concluded that ACL injury prevention programs must control specific combinations of loads such as those incurred during a combined valgus-anterior loading situation. Markolf et al measured in vitro forces in the ACL during combined loading states in cadaveric knees.[18] Increases in ACL forces

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were reported when a valgus or varus moment was applied with an anterior tibial load compared with those measured when an anterior tibial load only was applied. In addition, high valgus or varus moments increase the risk for medial or lateral tibiofemoral joint lift off and the potential for a knee ligament rupture.[18]

It is not known if one can extrapolate these biomechanical data to an increased risk of ACL injury when an athlete lands in a valgus position with little distance separating the right and left knees. One problem is that no study we are aware of has measured the distance of separation between the hips, knees, and ankles on landing or during acceleration into a vertical jump in the coronal plane. In addition, no data are available that demonstrate if a significant difference exists between young male and female athletes regarding the separation distance of the knee and ankle joints (relative to the hip joint) in the coronal plane on landing from a drop-jump. Finally, no investigation has determined if a neuromuscular training program can change lower limb alignment on landing.

The goal of this investigation was to devise a simple videographic test that would measure the distance between the hips, knees, and ankles in the coronal plane. An additional objective was that the test use standard equipment so that it could be performed outside a formal laboratory. The rationale for the development of this test was based on a prior study[12] in which landing mechanics and lower extremity strength were assessed in young athletes using a video-based optoelectronic digitizer that measured motion and a multicomponent force plate that measured ground reaction forces. The adduction or abduction moments about the knee joint were found to be significant predictors of peak landing forces ($P = .006$). These moments increase the risk of medial or lateral femoral condylar lift off, affecting tibiofemoral contact-stabilizing forces.[18] Although we realize that a simple assessment of lower limb position on landing using a single-plane videographic test cannot provide knee moment and peak landing force data, we believe that the drop-jump test can provide a general indicator of an athlete's ability to control lower limb axial alignment in the coronal plane.

The first hypothesis of this study was that the majority of female athletes would demonstrate abnormal (decreased) knee separation distances on landing and acceleration into a vertical jump. Second, it was hypothesized that the majority of male athletes would demonstrate a more neutrally aligned lower limb position with a greater amount of separation distance between the knees and ankles on landing and acceleration into a vertical jump. Third, it was thought that female athletes would have significantly greater knee separation distance after participation in a neuromuscular training program.

MATERIALS AND METHODS

Population

A total of 325 female and 130 male athletes underwent videographic testing to provide normal data on competitive volleyball, basketball, soccer, and gymnastic participants. Athletes were recruited from area high schools and youth soccer leagues. The mean age of the female subjects was 14.1 ± 1.7 years (range, 11-18 years), and the mean age of the male subjects was 14.6 ± 2.0 years (range, 11-19 years). Before the video test, all athletes were questioned regarding prior lower extremity injuries and screened to exclude history of prior lower extremity injuries or current symptoms of pain, patellar instability, or visible joint effusion. General demographic data were collected, including history of athletic participation and current participation. Informed consent was obtained from each athlete before testing.

Female participants were provided with information regarding a 6-week Sportsmetrics (Cincinnati Sportsmedicine Research and Education Foundation, Cincinnati, Ohio) neuromuscular training program designed and previously demonstrated to reduce injuries specifically in young female athletes.[11,12] The training sessions lasted approximately 1 hour per day, 3 days per week on alternating days, and they consisted of stretching, plyometric jump training, and weight training. The jump training was divided into 3 phases, consisting of a technique phase (first 2 weeks), a fundamentals phase (next 2 weeks), and a performance phase (final 2 weeks). Athletes were educated during each training session to maintain neutral alignment from their heads to their heels, with exaggerated hip and knee flexion, during jumping and landing tasks. Certified trainers used verbal and visual feedback to instruct the athletes to keep their heels directly under their hips, with toes and knees pointed forward at all times during landing and takeoff. Athletes were encouraged to land initially with their body weight on the forefoot and then to transfer the load onto their heels while maintaining postural control and hip and knee flexion angles.

Sixty-two female athletes agreed to participate (with parental approval and informed consent) and completed the training program. Participation was strictly voluntary, and no attempt was made to influence certain athletes over others to complete the training with respect to the results of video testing. These 62 female athletes underwent a second videographic test within 7 days of completion of training. Isokinetic knee flexion and extension testing was also conducted on 54 females before and after training (Biodex Medical Systems Inc, Shirley, NY). Peak torque values were obtained from 10 repetitions done on each leg at 300°/s, were normalized for body weight, and were corrected for gravity.

Video Test Description

A Sony Mini DV Camcorder equipped with a memory stick (Sony Products, Park Ridge, NJ) was placed on a stand that was 102.24 cm (40.25 in) in height. The stand was positioned approximately 365.76 cm (12 ft) in front of a box that was 30.48 cm (12 in) in height and 38.1 cm (15 in) in width. Also, 1-in Velcro circles (VELCRO USA Inc, Manchester, NH) were placed on each of the 4 corners of the box that faced the camera.

Athletes were instructed to wear fitted, dark shorts and low-cut gym shoes. Reflective markers were placed at the greater trochanter and the lateral malleolus of both the right and left legs, and Velcro circles were placed on the center of each patella. A research assistant demonstrated the jump-land sequence to each athlete, and 1 trial was conducted to ensure complete understanding of the test. The athletes were not provided with any verbal instruction regarding how to land or jump, only to land straight in front of the box to be in the correct angle for the camera to record properly. The athletes then performed a jump-land sequence by first jumping off the box, landing, and immediately performing a maximum vertical jump. This sequence was repeated 3 times.

After completion of the test, a research assistant viewed all 3 trials, and the one that best represented the athlete's jumping ability was selected for measurement. Advancing the video frame by frame, the following images were captured as still photographs: (1) preland, the frame in which the athlete's toes just touched the ground after the jump off of the box; (2) land, the frame in which the athlete was at the deepest point; and (3) takeoff, the frame that demonstrated the initial forward and upward movement of the arms and the body as the athlete prepared to perform the maximum vertical jump.

The preland frame was selected because it represented the most fully extended position of the knee while the athlete was still controlling the width of the stance. The land position was chosen to represent the most out-of-control position during landing, and it was the deepest point of knee flexion. The takeoff frame was assessed because we found that in many athletes, a change transpired in the coronal knee displacement as further differences in knee separation distance occurred as the athlete prepared to jump.

The captured images were imported into the hard drive of a desktop computer and digitized on the computer screen. A calibration procedure was accomplished by placing the cursor and clicking in the center of each Velcro marker on each of the 4 corners of the drop-jump box. The anatomical reference points represented by the reflective markers were selected by clicking in a designated sequence the cursor for each image. For the preland image, the sequence of selection was right hip, right knee, right ankle, left hip, left knee, and left ankle.

We analyzed the absolute centimeters of separation distance between the right and left hip and normalized separation distances for the knees and ankles, standardized according to the hip separation distance. Normalized knee separation distance was calculated as knee separation distance/hip separation distance, and normalized ankle separation distance was calculated as ankle separation distance/hip separation distance (Figure 1).

We also attempted to measure, in all of the male athletes and in 100 of the female athletes, the frontal angle (varus or valgus alignment) of the lower extremities. The frontal angle was determined during the takeoff frame by selecting the center of the midfemur, the center of the patella, and the center of the talocrural joint (in line with the lateral malleolus). We realized that the frontal angular measurements would not represent true osseous alignment and that the coronal measurements could be affected by lower limb internal and external tibial and femoral rotations and translations. The resulting data demonstrated that these angular measurements could not be accurately and reliably determined, and we therefore eliminated this analysis from the study.

Statistical Analyses

The means and SDs for the absolute centimeters of knee and ankle separation distance and for the normalized knee and ankle separation distance were calculated.

Linear regressions were performed to determine if correlations existed between knee and ankle separation distances during preland, land, and takeoff. Analysis of variance (ANOVA) was used to determine if correlations existed between knee flexion and extension peak torque and normalized knee and ankle separation distances. Unpaired Student t tests were used to determine if significant differences existed between male and female subjects for normalized knee and ankle separation distances. The ANOVAs were also used to determine if significant differences existed within gender between the age categories of 11 to 13, 14 to 16, and 17 to 18 years for normalized joint separation distances.

Paired t tests were used to determine if significant differences existed between pretrained and posttrained data in the 62 trained female athletes. Also, χ^2 analyses compared the distribution of patients before and after training for those with ≤60% normalized knee separation distance, 61% to 80% normalized knee separation distance, and >80% normalized knee separation distance during preland, land, and takeoff. These percentile groups were chosen arbitrarily, but we believed that 60% represented a distinctly abnormal lower limb valgus alignment in the coronal plane, which was visually evident from the test photographs.

Reliability was determined using intraclass correlation coefficients (ICCs). Correlation coefficients between test-retest data had to be greater than 0.70, the standard for adequate reliability.[5] Seventeen female athletes underwent the videographic test twice, 7 weeks apart. For these data, we evaluated the reliability of the absolute centimeters of hip separation distances. Hip separation distance was expected to be highly reliable, thus providing the basis for normalization of knee and ankle separation distances. Then, in 10 other subjects, reliability within the videographic test was assessed by capturing 2 of the 3 jump-land sequence trials and comparing the absolute centimeters of hip, knee, and ankle separation distances between the 2 sequences on the same day of testing.

Power and sample size calculations were done to evaluate the primary study findings—the effect of training on absolute knee separation distance and normalized knee separation distance. With 62 trained females in this study, it was found that this investigation had sufficient power (90%) to detect significant differences at a level of .05.

RESULTS

Reliability Testing

For the test-retest trial, the ICCs for the hip separation distance demonstrated high reliability (preland, 0.96;

land, 0.94; takeoff, 0.94). For the within-test trial, the ICCs for the hip, knee, and ankle separation distance were all ≥0.90, demonstrating excellent reliability of the videographic test and software capturing procedures.

Female Subjects: Findings Before Neuromuscular Training

There was no statistically significant effect of age or lower limb dominance in the female subjects for the normalized mean knee and ankle separation distances for each phase of the jump-land sequence.

The absolute hip separation distance was 41 ± 3 cm on prelanding, landing, and takeoff.

The absolute knee separation distance was 28 ± 6 cm on prelanding, 23 ± 9 cm on landing, and 23 ± 9 cm on takeoff. The normalized knee separation distance on prelanding was 63% ± 14%; on landing, 51% ± 19%; and on takeoff, 50% ± 18% (Figure 2).

The absolute ankle separation distance was 40 ± 8 cm on prelanding, 35 ± 8 cm on landing, and 34 ± 8 cm on takeoff. The normalized ankle separation distance on prelanding was 92% ± 20%; on landing, 79% ± 20%; and on takeoff, 78% ± 19% (Figure 3).

There was no correlation between knee and ankle separation distances for each of the jump-land sequences. A knee separation distance of ≤60% was found on prelanding in 44% of the female athletes; on landing, in 77%; and on takeoff, in 80%.

Male Subjects

There was no statistically significant effect of age or lower limb dominance in the male subjects for the normalized mean knee and ankle separation distances for each phase of the jump-land sequence.

The absolute hip separation distance was 44 ± 5 cm on prelanding and 42 ± 5 cm on landing and on takeoff.

The absolute knee separation distance was 26 ± 5 cm on prelanding, 22 ± 8 cm on landing, and 23 ± 8 cm on takeoff. The normalized knee separation distance on prelanding was 59% ± 11%; on landing, 51% ± 15%; and on takeoff, 53% ± 15% (Figure 2).

The absolute ankle separation distance was 36 ± 6 cm on prelanding, 31 ± 6 cm on landing, and 31 ± 6 cm on takeoff. The normalized ankle separation distance on prelanding was 83% ± 14%; on landing, 75% ± 15%; and on takeoff, 74% ± 15% (Figure 3).

There was no correlation between knee and ankle separation distances for each of the jump-land sequences. A knee separation distance of ≤60% was found on prelanding in 57% of the male athletes; on landing, in 75% (Figure 4); and on takeoff, in 72%.

Comparison of Female to Male Subjects

There was no statistically significant difference between male and female subjects in the mean normalized knee and ankle separation distance during the landing and takeoff phases (Figures 2 and 3). Female athletes demonstrated significantly higher mean knee and ankle normalized separation distances during the preland phase only.

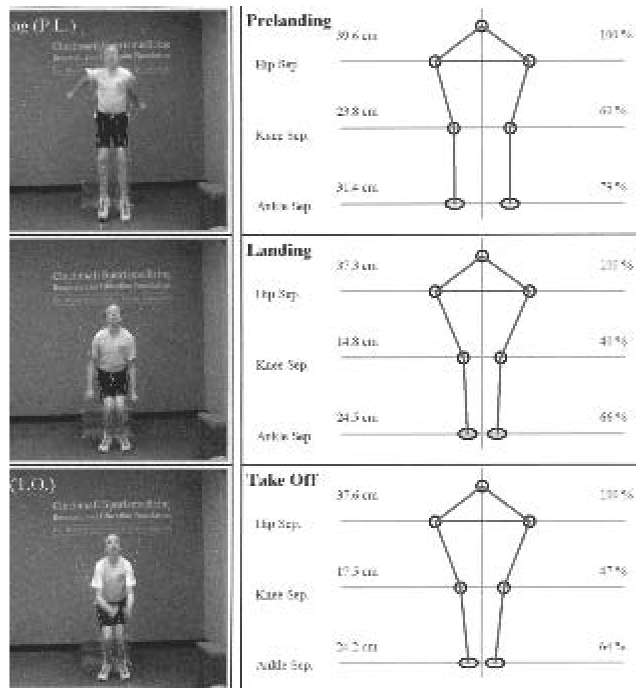

Figure 1. The videographic test produced photographs of 3 phases of the drop-jump test. The centimeters of distance between the hips, knees, and ankles were calculated along with normalized knee and ankle separation distance (according to the hip separation distance). Shown is the test result of a 14-year-old female subject before Sportsmetrics neuromuscular training. Sep, separation.

Effect of Neuromuscular Training in Female Athletes

Statistically significant increases were found after training in the subgroup of 62 female athletes in the absolute and normalized knee (Figure 2) and ankle (Figure 3) separation distances for all phases of the jump-land sequence ($P < .001$). After training, female athletes had statistically greater mean normalized knee and ankle separation distances than those of males for all phases of the jump-land sequence ($P < .0001$).

After training, a statistically significant difference was found in the distribution of female athletes who had ≤60%, 61% to 80%, and >80% knee separation distance on landing ($P = .003$) (Figure 4) and takeoff ($P = .006$). The distribution in the percentage change in knee and ankle separation distances after training is shown for all 3 phases of the jump-land sequence in Table 1.

We separately analyzed 39 of these 62 female athletes (63%) who had ≤60% knee separation distance on landing before training. After completion of the training program, 23 of these 39 female athletes (59%) improved and landed with >60% knee separation distance.

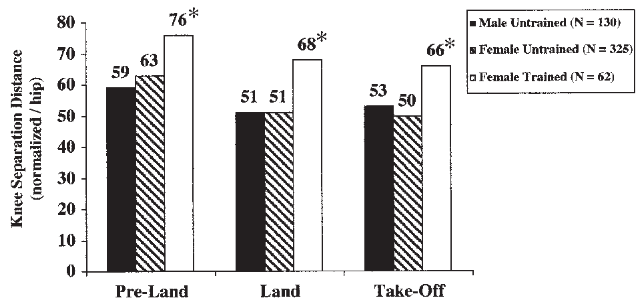

Figure 2. The mean normalized knee separation distances for the 3 phases of the drop-jump test are shown for the male athletes, untrained female athletes, and trained female athletes. After training, female athletes had statistically significant increases in the mean normalized knee separation distance in all 3 phases ($P < .001$) and had statistically greater mean normalized knee separation distances than those of male athletes for all phases ($P < .0001$). Asterisks denote statistically significant difference.

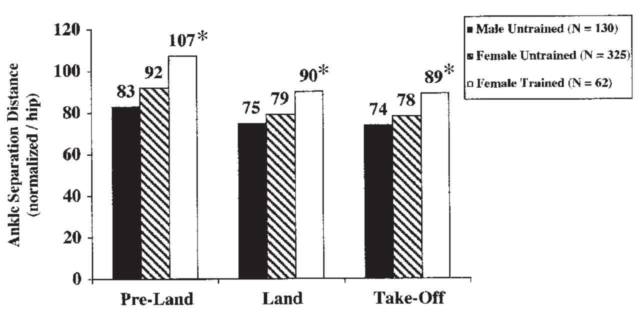

Figure 3. The mean normalized ankle separation distances for the 3 phases of the drop-jump test are shown for the male athletes, untrained female athletes, and trained female athletes. After training, female athletes had statistically significant increases in the mean normalized ankle separation distance in all 3 phases ($P < .001$) and had statistically greater mean normalized ankle separation distances than those of male athletes for all phases ($P < .0001$). Asterisks denote statistically significant difference.

Statistically significant improvements were noted after training in knee flexion peak torque ratio values in both the dominant and nondominant legs ($P < .0001$). In the dominant leg, mean knee flexion peak torque increased from 40% ± 8% N•m/BW before training to 44% ± 7% N•m/BW after training, and in the nondominant leg, it increased from 38% ± 8% N•m/BW before training to 43% ± 9% N•m/ BW after training.

Knee extension peak torque ratio improved slightly in both the dominant and nondominant lesgs, but this effect was not statistically significant. In the dominant leg, peak torque improved from 49% ± 8% N•m/BW to 51% ± 8% N•m/BW.

Statistically significant improvements were noted in the hamstrings-quadriceps ratio for the nondominant leg, which increased from 73% ± 15% before training to 83% ± 15% after training ($P = .001$). There was no significant

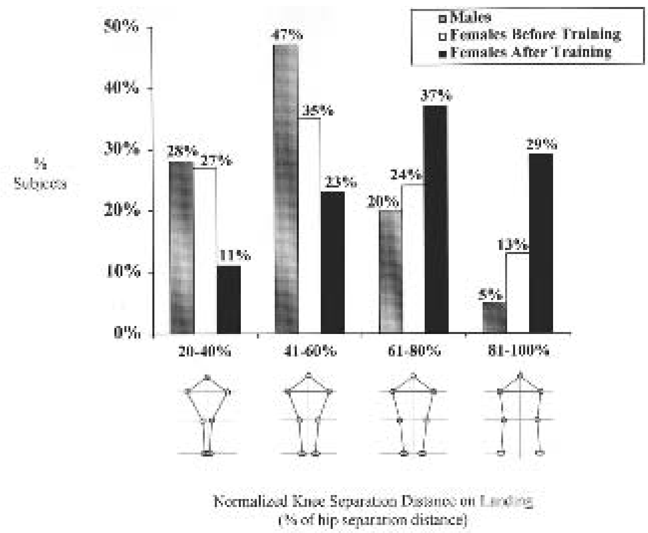

Figure 4. The distribution of male athletes and the 62 female athletes before and after training according to normalized knee separation distance on landing. Although there was no difference in the distribution of male and untrained female athletes among the categories shown, a significant difference was present between male athletes and trained female athletes ($P < .0001$). The stick figures are representative of the knee separation distance but not of the ankle separation distance.

increase in the hamstrings-quadriceps ratio for the dominant leg (pretraining, 83% ± 20%; posttraining, 88% ± 14%). There were no correlations between peak torque flexion and extension values and normalized knee and ankle separation distances for any phase of the jump-land sequence before or after training.

DISCUSSION

We developed and studied a drop-jump landing procedure to record lower limb axial alignment in the coronal plane using a single standard video camera. The results of test-retest data in a subgroup of subjects were found to be reliable with high correlation coefficients (ICC > 0.90). The testing procedure was designed to be relatively easy to perform by researchers, coaches, trainers, or therapists in any facility. We developed this test to provide a general indicator of an athlete's lower limb axial alignment in the coronal plane in a straightforward drop-jump and vertical takeoff task. We do not propose that this test can be used as a risk indicator for knee ligament injury. We recognize that the video analysis only depicts hip, knee, and ankle positions in a single plane during one maneuver and that noncontact ACL injuries may occur in side-to-side or cutting motions. A more sophisticated multicamera system would be required to measure these types of motions. Even the use of just a second camera to measure the degrees of knee flexion on landing would provide additional information[13]; however, our goal was to use one camera to make the measurements easier to perform from a screening standpoint.

TABLE 1
Change in Normalized Knee and Ankle Separation Distances After Neuromuscular Training in 62 Female Athletes

	Preland				Land				Takeoff			
	Knee		Ankle		Knee		Ankle		Knee		Ankle	
% Change	n	%	n	%	n	%	n	%	n	%	n	%
None	24	38	27	44	21	33	33	53	22	35	35	56
5-10	12	19	9	15	11	18	3	4	8	13	1	2
11-15	9	15	8	13	5	8	5	8	7	11	8	13
16-20	9	15	3	4	6	10	9	15	4	6	6	10
>20	8	13	15	24	19	31	12	19	21	34	12	19

(continued)

Figure 5. The drop-jump takeoff sequences from 3 female athletes before and after neuromuscular training. Athlete A, a 14-year-old basketball player, demonstrated marked improvement in knee separation distance (from 17 cm to 37 cm) and in ankle separation distance (from 24 cm to 36 cm) after training. The normalized knee separation distance improved from 47% to 92%, and the normalized ankle separation distance improved from 64% to 92%.

We hypothesized that the majority of untrained female athletes would demonstrate an abnormal lower limb position on landing from a drop-jump and on acceleration into a vertical jump. Authors have reported that 58% to 61% of noncontact injuries occur during landing from a jump.[7,8] The final position of the knee joint on landing is influenced by the center of gravity of the upper body and the trunk over the lower extremity. Equally important are the trunk-hip adduction or abduction position, foot-ankle pronation-supination position, and foot separation distance. These

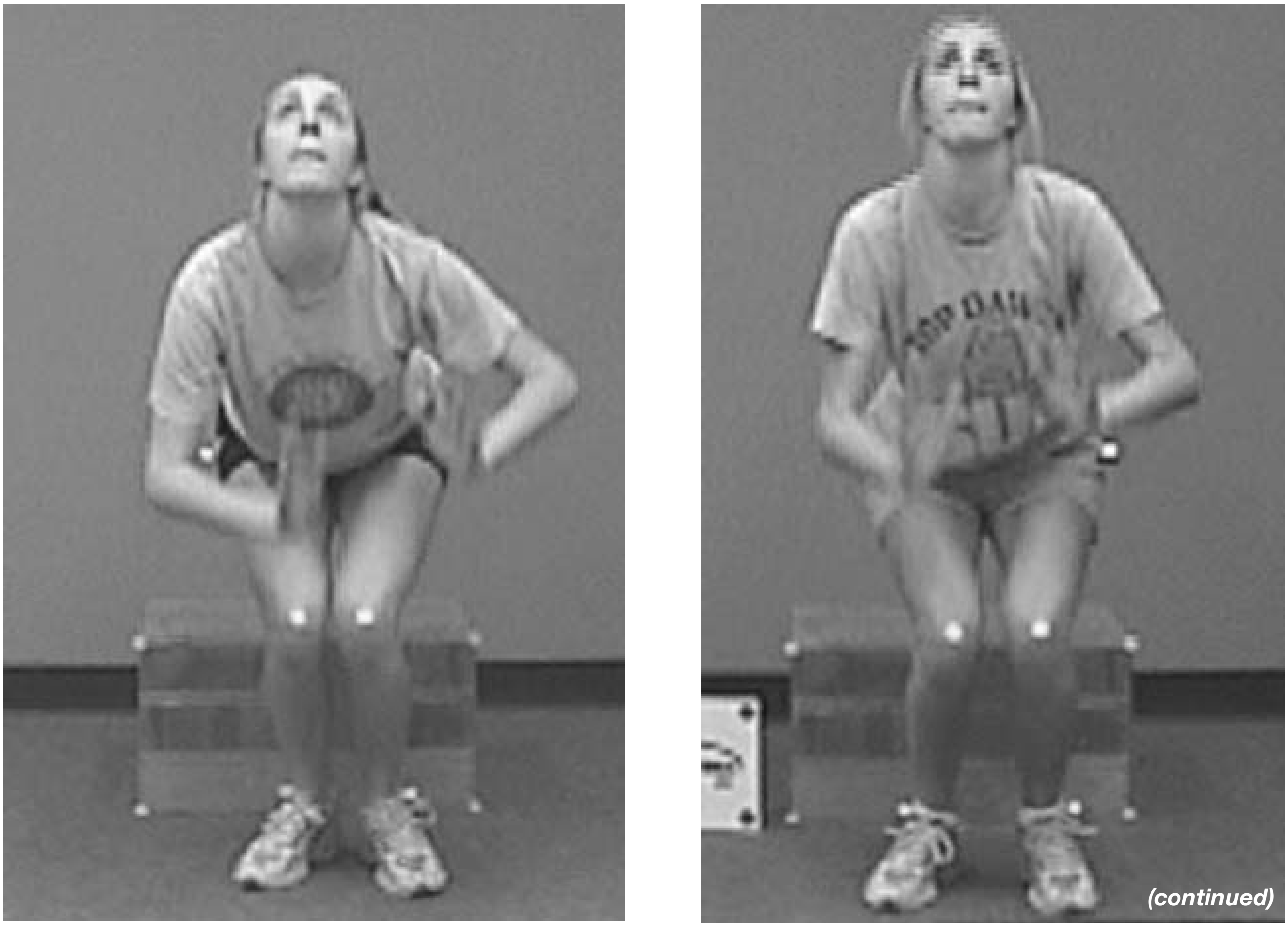

Figure 5 (continued). Athlete B, a 14-year-old volleyball player, demonstrated poor upper body position and no improvement in knee or ankle separation distance after training. She was encouraged to pursue additional training.

effects sum to produce either a varus or valgus moment about the knee joint, which must be balanced by lower limb musculature.[12] If the athlete is off-balance or has contact with another player, a loss of trunk and lower limb control and position may occur, and the knee joint may go into an extended, hyperextended, or valgus position. The knee position measured in the coronal plane in our single-plane video analysis is a reflection of rotations in both the coronal and transverse planes (internal-external femoral and tibial rotation). Our test did not distinguish between these individual motions, as this requires more sophisticated instrumentation.[12]

The data in this study showed that a normalized knee separation distance of <60% occurred in 77% of untrained female subjects on landing and in 80% on takeoff. Although there are many potential mechanisms for ACL injury, it has been postulated that excessive valgus moments about the knee joint with subsequent high anterior tibial shear forces may be one of the ACL injury mechanisms in females.[9,15,17] Excessive valgus loading may result in decreased tibiofemoral contact, or condylar lift-off,[18] and a reduction in the normal joint contact geometry that contributes to knee joint stability. This position, coupled with a highly activated quadriceps muscle that produces maximum anterior shear forces with the knee joint at low flexion angles (0°-30°),[4,10,22] could potentially lead to ACL rupture.

Hamstring muscle activation with the knee joint at or near full knee extension (0°-30°) produces insufficient posterior tibial shear forces to protect the ACL because of the small angle of inclination of the hamstring tendons.[25] Noyes and Sonstegard found a decreased mechanical advantage of the inner hamstrings with knee extension, with the flexion force at 0° approximately one half of that at 90°.[21] Similarly, the rotation force of the inner hamstrings declined with knee extension, with the rotation force at 0° being 41% that of the rotation force at 90°. A rotation "wind-up" effect was found, in which the internal tibial rotation forces increased significantly with external tibial rotation because of an increase in muscle mechanical advantage.

We hypothesized that the majority of young male athletes would demonstrate a neutrally aligned lower limb position on landing and on acceleration into a vertical jump. This hypothesis was not supported, as 75% of the male athletes had marked decreases in knee separation

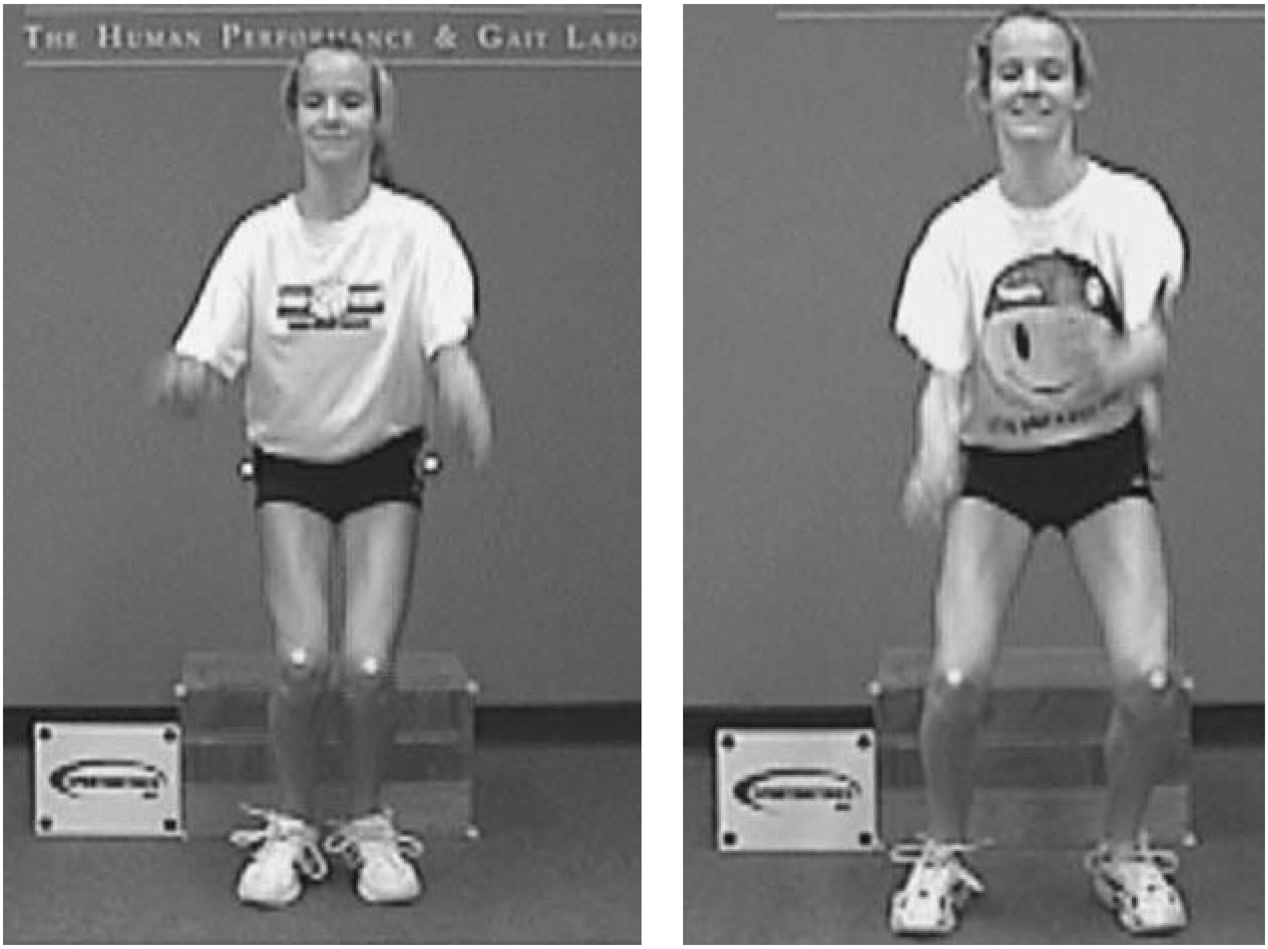

Figure 5 (continued). Athlete C, a 12-year-old basketball player, showed slight overcorrection from a valgus position (knee separation distance, 14 cm) before training to a varus position (knee separation distance, 37 cm) after training. The normalized knee separation distance improved from 38% to 98%. The normalized ankle separation distance improved dramatically from 65% to 111%.

distances on landing and 72% had marked knee separation distances on takeoff, indicating a valgus-aligned lower limb position. The significance of this finding is unknown and may represent an aberration requiring further study. It may be that this single-plane video test was not sensitive enough to depict relevant differences in landing patterns between the sexes. Other studies that used multicamera systems or force plates to investigate the drop-jump test found significant differences between female and male subjects regarding knee flexion angles,[13] knee extension moments,[3,12] knee valgus moments,[3] and ground reaction forces.[12] A prior investigation determined that untrained female athletes had lower knee extension moments than did males and postulated that this was explained by the male subjects' high use of the hamstrings as a knee flexor at landing.[13]

We hypothesized that a neuromuscular training program (Sportsmetrics) would increase knee separation distance in female athletes. The goals of the training program were to teach athletes to control upper body, trunk, and lower body position; lower the center of gravity by increasing hip and knee flexion on landing; and develop muscular strength and techniques to land with decreased ground reaction forces. In addition, athletes were taught to preposition the body and lower extremity before landing so they could land in the position of greatest knee joint stability and stiffness, with the goal of obtaining a more normal ankle and knee separation distance, within approximately 80% of the hip separation distance. Sportsmetrics was previously shown to be effective in inducing changes in neuromuscular indices.[12] These included decreased peak landing forces of 22%, decreased peak adduction and abduction moments of 50%, and increased hamstrings-quadriceps muscle peak torque ratios of 26% (nondominant side) and 13% (dominant side). The ability of the athlete to control knee adduction and abduction moments highly correlated as a predictor of peak landing forces (P = .006). Decreased adduction or abduction moments may decrease the risk of liftoff of the medial or lateral femoral condyle, improve tibiofemoral contact stabilizing forces,[18] and decrease the risk of ligament injury. Other training techniques that used verbal and visual feedback have also

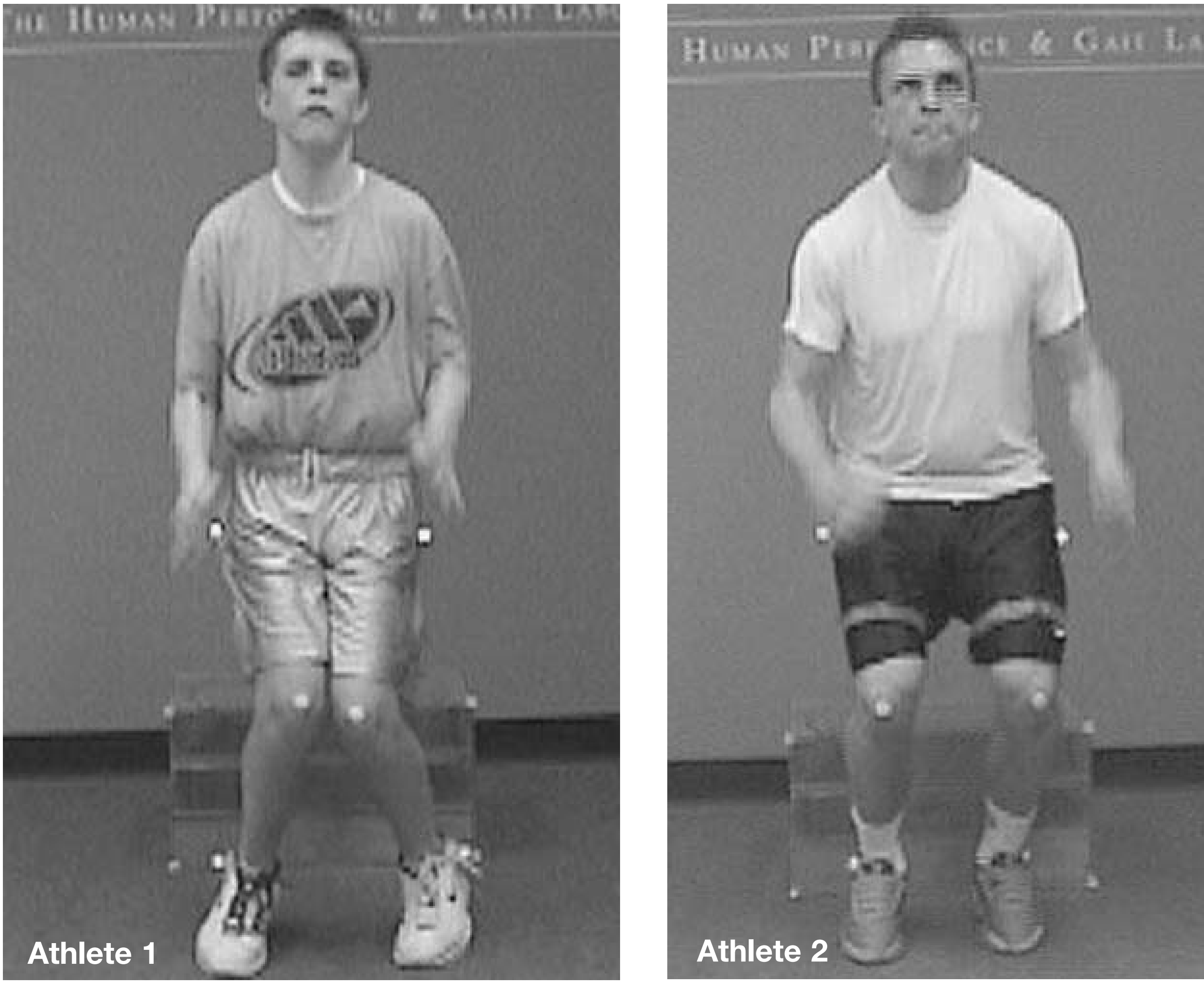

Figure 6. The drop-jump takeoff sequences from 3 male athletes. Athlete 1, a 12-year-old soccer player, demonstrated a poor knee separation distance of 10.6 cm (28% normalized). Athlete 2, a 17-year-old basketball player, demonstrated a knee separation distance of 29.3 cm (65% normalized).

been successful in reducing ground reaction forces.[6,16,19,24,26]

The results of our study demonstrated that after training statistically significant increases were found in the absolute centimeters and normalized knee and ankle separation distances for all phases of the jump-land sequence ($P < .001$). After training, female subjects had statistically greater normalized knee and ankle separation distances than males for all phases of the jump-land sequence. Sportsmetrics was shown in a prior study to be effective in decreasing the incidence of noncontact serious knee ligament injuries in female athletes.[11] In that report, 8 of 463 untrained female athletes sustained a serious noncontact knee ligament injury, compared with 0 of 366 trained female athletes and 1 of 434 untrained male athletes. Untrained female athletes had an incidence of knee injury 3.6 times higher than that of trained female athletes ($P = .05$) and 4.8 times higher than that of male athletes ($P = .03$). It is unknown from the current study if the improvement in knee separation distance after training transfers over to reduce the risk of a serious knee ligament injury in female athletes. We believe the increased incidence of knee injuries in female athletes is multifactorial, and it is currently unknown which factors are dominant and which play a negligible role. A number of intrinsic factors inherent in women have been suggested, including a narrow intercondylar notch, small-sized ACL, pelvic-hip-knee-foot alignment, generalized knee laxity, foot pronation, and hormonal variations.[9] Extrinsic factors related to athletic conditioning, skill, training, and equipment have also been discussed. Although issues related to differences in neuromuscular control, muscle reaction patterns,[14,27] coordination and control of body, and lower extremity positions during athletics are usually related to extrinsic factors, it may be that these factors are both intrinsic and extrinsic in their development.

It is important to note that when we separately analyzed 39 of the 62 (63%) female athletes who had ≤60%

Figure 6 (continued). A neutral alignment is evident in athlete 3, a 16-year-old football player, who demonstrated a knee separation distance of 38.4 cm (82% normalized).

knee separation distance on landing before training, only 23 (59%) improved and landed with >60% knee separation distance (Figures 5 and 6). Therefore, some female athletes may require further training to demonstrate improvements in knee and ankle separation distance and to land in a more neutrally aligned position. The pictorial sequence of the filmed drop-jump provides important information to the athletes, parents, and coaches, and it can be useful in detecting athletes who require, in our opinion, further neuromuscular training.

ACKNOWLEDGMENT

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