THE DROP-JUMP VIDEO SCREENING TEST: RETENTION OF IMPROVEMENT IN NEUROMUSCULAR CONTROL IN FEMALE VOLLEYBALL PLAYERS

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ABSTRACT

Barber-Westin, SD, Smith, ST, Campbell, T, and Noyes, FR. The drop-jump video screening test: retention of improvement in neuromuscular control in female volleyball players. J Strength Cond Res 24(11): 3055–3062, 2010—A valgus lower limb alignment is commonly documented during noncontact anterior cruciate ligament injuries. We previously developed a videographic drop-jump test to measure overall lower limb alignment in the coronal plane as a screening tool to detect such an abnormal (valgus) position on landing. A neuromuscular retraining program developed for female athletes was shown to be effective in improving lower limb alignment on this test immediately after completion of training. What remained unknown was whether these improvements would be retained for longer periods of time. Therefore, this study was undertaken to determine if these improvements in overall lower limb alignment would be retained up to 1 year after the training. Sixteen competitive, experienced female high-school volleyball players underwent the video drop-jump test and then completed the neuromuscular retraining program. The program consisted of a dynamic warm-up, jump training, speed and agility drills, strength training, and static stretching and was performed 3 times a week for 6 weeks. The athletes repeated the drop-jump test immediately upon completion of training and then 3- and 12-months later. Significant improvements were found in the mean normalized knee separation distance between the pre and posttrained values for all test sessions ($p < 0.01$). Immediately after training, 11 athletes (69%) displayed significant improvements in the mean normalized knee separation distance that were retained 12 months later. Five athletes failed to improve. The video drop-jump test, although not a risk indicator for a knee ligament injury, provides a cost-effective general assessment of lower limb position and depicts athletes who have poor control on landing and acceleration into a vertical jump.

KEY WORDS: limb alignment, valgus screening, female athletes

INTRODUCTION

It is well known that adolescent and adult female athletes have a 4- to 8-fold higher incidence of sustaining a serious noncontact knee ligament injury compared to male athletes participating in the same sport (1,10,11). The factors responsible for the disparity between women and men in anterior cruciate ligament (ACL) injury rates are controversial and remain scientifically undefined. Theories have included inherent differences in anatomic and hormonal variables (10,16), but published studies are inconclusive and their findings are contradictory. Many authors have speculated that altered neuromuscular control and strength of the lower extremity are responsible for this problem (7,15,17,18,27–29). Differences between female and male athletes in movement patterns; muscle strength, activation, and recruitment patterns; and knee joint stiffness have been demonstrated under controlled, pre-planned, and reactive conditions in the laboratory (3).

Studies have shown that a valgus lower limb alignment commonly occurs during noncontact ACL injuries, frequently either when an athlete lands from a jump or attempts to accelerate into a jump (6,8,9). Previous investigations have examined differences between men and women in knee flexion angles (17) and ground reaction forces on the lower extremity upon landing (15,21,23,24,26). One investigation reported that a valgus torque combined with an anterior tibial force in a cadaver model resulted in a statistically significant larger strain in the ACL than an anterior force alone ($p < 0.0001$) (5). The authors concluded that ACL injury prevention programs for female athletes must control combinations of loads such as those incurred during a combined valgus-anterior loading situation.

We previously described a simple videographic drop-jump test that measures the distance between the hips, knees, and ankles in the coronal plane, which was developed to be used as a general indicator of an athlete’s ability to control lower
limb axial alignment on landing (Figure 1) (22). The test uses a single camera and is relatively easy to perform by researchers, coaches, trainers, or therapists in any facility. We do not propose that this test can be used as a risk indicator for knee ligament injury but as a screening tool to detect athletes who demonstrate an abnormal (valgus) lower limb position on landing from a drop jump.

The video drop-jump test was previously conducted on 325 female and 130 male high-school athletes (22). Sixty-two of the female athletes underwent 6 weeks of neuromuscular retraining in a supervised program (Sportsmetrics™) that had been reported to significantly reduce the risk of a noncontact knee ligament injury in high-school female athletes (2,12,15). The athletes underwent the drop-jump test again within 1 week of completion of training. Statistically significant increases were found after training in the absolute and normalized knee and ankle separation distances for all phases of the jump-land sequence ($p < 0.001$), reducing the number of athletes who demonstrated an abnormal lower limb position from 77 to 34%.

Although the neuromuscular retraining program studied in our investigation was effective in improving the overall lower limb alignment on the drop-jump test in two-thirds of the female athletes, it is unknown whether the improvements are retained over a longer period of time. Therefore, the purpose of this investigation was to determine if female athletes retained improvements in overall lower limb alignment on the video drop-jump test up to 1 year after completion of the neuromuscular training program. To our knowledge, this is the first study to investigate this question. We hypothesized that those athletes who improved their overall lower limb alignment on the video drop-jump test immediately after 6 weeks of neuromuscular retraining would show similar results in this test up to 1 year later.

**METHODS**

**Experimental Approach to the Problem**

This study was undertaken to determine if immediate improvements in overall lower limb alignment in adolescent female athletes on a video drop-jump test after a 6-week previously published neuromuscular retraining program (2,15) would be retained up to 1 year later. A video drop-jump test with proven reliability that measures the distance between the hips, knees, and ankles in the coronal plane and provides an indicator of an athlete’s ability to control lower limb axial alignment on landing was used to address the study hypothesis. The athletes who participated in this study were experienced, competitive female volleyball players who played high-school and club-level leagues year round. All subjects underwent the video drop-jump test 1 week before the neuromuscular training program was initiated. The

![Figure 1](https://example.com/figure1.png)

Figure 1. The 3 phases of the drop-jump video screening test are shown on the printout that is given to the athletes. The absolute centimeters of distance between the hips, knees, and ankles are shown on the left of the stick figures, whereas the normalized knee and ankle separation distances are shown on the right. During the landing phase, this subject demonstrated a 22% normalized knee separation distance. The overall valgus lower limb alignment is clearly demonstrated in the photographs.
Subjects

All testing and training procedures were fully explained, and written informed parental consent was obtained for each subject. The study was approved by the Internal Review Board for use of human subjects at the hospital where the testing was conducted. Sixteen competitive female volleyball players from 2 area high schools (mean age 14.6 ± 0.7 years, range, 13–16 years; mean height 1.69 ± 0.03 m, range, 1.63–1.78 m; mean weight 58 ± 6 kg, range, 49–77 kg) voluntarily participated in this study. All subjects had no history of knee injury or pathology and had no symptoms of pain, patella instability, or visible joint effusion. All subjects had participated in competitive volleyball for a minimum of 2 years before this study was initiated. The neuromuscular training was conducted at the 2 high schools upon the conclusion of the summer club-level season and just before the start of the fall high-school season. All subjects participated in their high-school volleyball season directly upon completion of training and then played club-level volleyball for the remainder of the study period. None of the athletes underwent any other formal strength or neuromuscular training programs in the 1-year duration of this study.

Procedures

Video Drop-Jump Test. The video drop-jump test was previously described in detail (22). A standard video camcorder was positioned approximately 366 cm in front of a box that was 30 cm in height and 38 cm in width. Reflective markers were placed at the greater trochanter, the lateral malleolus, and the center of the patellae on both the right and left legs. The subjects performed a drop-jump by first jumping off the box, landing, and immediately performing a maximum vertical jump. No specific instructions were provided regarding how to land or jump; the subjects were only instructed to land straight in front of the box to be in the correct angle for the camera to record properly. This sequence was repeated 3 times.

The following images were captured: (a) preland, the frame in which the subjects’ toes just touched the ground after the jump off of the box; (b) land, the frame in which the subjects were at the deepest point; and (c) take-off, the frame that demonstrated the initial forward and upward movements of the arms and the body as the subjects prepared to perform the maximum vertical jump.

The absolute centimeters of separation distance between the right and left hips, knees, and ankles was measured as previously described (22). The distance between the knees and ankles was then normalized according to the hip separation distance. We compared the distribution of subjects who had ≤60% normalized knee separation distance, 61–80%, and >80% during preland, land, and take-off. We believed that 60% represented a distinctly abnormal lower limb valgus alignment position, which was visually evident from the captured photographs (Figure 1).

The reliability of the drop-jump test was reported previously (22). For test–retest trials, the interclass correlation coefficients (ICCs) for the hip separation distance demonstrated high reliability (preland, 0.96; land, 0.94; take-off, 0.94). For within-test trials, 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.

Neuromuscular Retraining Program. The Sportsmetrics (Cincinnati Sportsmedicine Research and Education Foundation, Cincinnati, OH, USA) program consisted of a dynamic warm-up, jump training, speed and agility drills, strength training, and static stretching (2). All training sessions were supervised by certified instructors; there were 3 sessions per week (on nonconsecutive days) for 6 weeks. Each session lasted approximately 90–120 minutes. During the jump training and speed and agility drills, subjects were encouraged to maintain a neutral alignment by reinforcing the knees and ankles to be placed hip distance apart with exaggerated knee and hip flexion on landing from a jump, decelerating and cutting. Trainers gave constant feedback on jump-land mechanics and decelerating, cutting, and pivoting technique. Terms such as “quiet landing,” “toes and knees forward,” “knees and feet directly under hips,” and “bend at the knees” were repeatedly used to aid in the re-education process. The jumps included a wall jump, tuck jump, squat jump, barrier jumps side-to-side and forward-back, 180° jump, bounding, scissors jump, single-leg hop, jump into bounding, and broad

<table>
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<tr>
<th>Time period comparison</th>
<th>Mean ± SD</th>
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<td>Pretrain vs. immediate posttrain</td>
<td>50 ± 16</td>
<td>−17</td>
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<td></td>
<td>67 ± 17</td>
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<tr>
<td>Pretrain vs. 3-month posttrain</td>
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<td>&lt;0.01</td>
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<tr>
<td>Pretrain vs. 12-month posttrain</td>
<td>74 ± 17</td>
<td>−24</td>
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jumps. The progression of this portion of the training program has been previously described in detail (2,15).

Strength training placed an emphasis on hamstring, hip flexion/abduction and core strength to aid in proper lower extremity alignment and muscle recruitment patterns. Two different strength training methods were used based on equipment availability at each school. Eight athletes performed strength training on the court with the use of resistance bands and body weight exercises. The other 8 athletes performed strength training in a weight room and incorporated machines, free weights, a cable system, and body weight exercises. Static flexibility exercises were performed at the end of each training session.

Statistical Analyses
Repeated-measures analysis of variance using the Tukey-Kramer Multiple Comparisons test was selected to determine if significant differences existed in the mean normalized knee separation distance values between testing sessions. A linear regression model was used to determine if an association was present between the number of training sessions completed and the normalized knee separation distance value at the 3 posttraining tests. Linear regression was also used to determine if an association existed between the athletes' height and weight and the normalized knee separation distance at the pretrain test and the 12-month posttrain test time periods. Paired t-tests were used to determine if significant differences occurred between the pretrain and 12-month posttrain test sessions for height and weight.
data were normally distributed (Kolmogorov–Smirnov test). Alpha was set to \( p \leq 0.05 \).

Power and sample size calculations were done to evaluate the effect of training on the normalized knee separation distances. With 16 subjects in this study, it was found that this investigation had sufficient power (>90%) to detect significant differences in normalized knee separation distances (at least 15 ± 1%) at a level of 0.05.

We classified the normalized knee separation distance as improved and retained if (a) the posttrained value was ≥20% more than the pretrained value and (b) the posttrained normalized knee separation distance was ≥60%. For athletes who demonstrated ≥60% normalized knee separation distance on their pretrain test, the posttrain test must have been ≥20% more than the initial test to be considered improved.

RESULTS

Significant improvements were found in the mean normalized knee separation distance between the pretrain and posttrained values for all test sessions (Table 1, Figure 2). The distribution of the subjects in the normalized knee separation distance categories demonstrated that although 75% had <60% knee separation distance before training, 31% had this value at the immediate posttrain and 3-month posttraining time periods, and only 19% had this value 12 months after training (Figure 3). There was no significant effect of the number of training sessions attended and the normalized knee separation distances during each posttraining period. Seven subjects completed 10–12 training sessions, 8 completed 13–15 sessions, and 1 completed 17 training sessions. There was no significant difference in the mean height or weight of the subjects between the pretrain test and 12-month posttrain test sessions. There was no association between the subjects’ height or weight and the normalized knee separation distance values at the pretrain test and 12-month posttrain test sessions.

The number of subjects that improved their normalized knee separation distance according to the study criteria at the 3 posttrain test sessions compared to their pretrain test value is shown in Figure 4. The pre and posttrained normalized knee separation distance values for the subjects who showed improvements are shown in Figure 5. In Figure 6, 3 subjects are shown who had smaller normalized knee separation distance values at the immediate posttrained test compared to the pretrained test, but then improved at the 3- and
12-month posttrained tests. Five subjects (31%) failed to demonstrate improvement or retention of initial improvements (Figure 7).

Eight subjects showed a continued improvement in their normalized knee separation distance over the 3 posttraining test sessions. The average percent improvement from the pretrain test value was 21% at the immediate posttrain test session, 34.5% at the 3-month posttrain session, and 57% at the 12-month posttrain session. There was no noteworthy difference in these 8 subjects in height or weight; only 2 subjects had increases in height (2.5 cm each) and only 2 other subjects gained weight (2.27–2.72 kg).

No subject sustained an injury during this study that resulted in loss of practice or playing time or that required formal medical attention.

**DISCUSSION**

A valgus lower limb alignment is frequently seen during noncontact ACL injuries, which commonly occurs either when an athlete lands from a jump or attempts to accelerate into a jump. We developed a video-graphic drop-jump test to measure the distance between the hips, knees, and ankles in the coronal plane to be used as a screening tool to detect an abnormal (valgus) lower limb position on landing. This study found, in a small group of adolescent female high-school volleyball players, significant improvements in the mean normalized knee separation distances between the pre and posttrained values for all test sessions ($p < 0.01$). Immediately after training, 11 athletes (69%) displayed significant improvements in their lower limb alignment that were retained 12 months later. Before training, 75% of the subjects had $<60\%$ knee separation distance, indicating poor overall lower limb control on this task. One year later, only 19% were in this category. The 5 athletes that failed to improve or retain their initial improvements in normalized knee separation distances were encouraged to continue neuromuscular and strength training if possible within the allowance of their volleyball training and season participation.

The drop-jump video test was designed to be cost effective and easy to perform by researchers, coaches, trainers, or therapists in any facility. This test only provides a general indicator of an athletes' lower limb axial alignment in the coronal plane in a straightforward drop-jump and vertical take-off task. Other investigators have reported similar testing protocols to measure this alignment (14,20). We agree with others that this type of drop-jump test cannot be used as a risk indicator for noncontact knee ligament injuries (25).
We recognize that this video test performed during 1 maneuver only depicts hip, knee, and ankle positions in a single plane, and that noncontact ACL injuries frequently occur in side-to-side, cutting, or multiple complex motions. More sophisticated and expensive multicamera systems are required to measure these types of motions in multiple planes. However, our test provides a general assessment of lower limb position and depicts those athletes who have poor control on landing and acceleration into a vertical jump. It is reliable, practical, and feasible for individuals who do not have funds or access to multiple cameras, force plates, and research personnel required to perform extensive data collection and reduction with more complex systems.

In a prior investigation (22), 77% of 325 untrained female athletes had ≤60% normalized knee separation distance on landing during the drop-jump test. Upon completion of the neuromuscular training program, this percentage decreased to 34%. The current study supports these data and demonstrates that, overall, 69% of the female athletes improved and retained the improvements 12 months after the completion of training. It is important to note that variability existed in the normalized knee separation distances among the athletes during the 3 posttrain test sessions for unknown reasons. Normal growth and maturation may account for the continued improvements noted in some athletes between the early posttrain and 12-month posttrain test sessions. However, other studies have found either no influence on maturation in female athletes on knee flexor and extensor peak torques (4) or a negative influence on neuromuscular control and lower extremity strength (13).

The goals of the neuromuscular 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. Additionally, athletes were taught to preposition the body and lower extremity before landing to land in the position of greatest knee joint stability and stiffness, with the goal of obtaining a more neutrally aligned ankle and knee separation distance. The data from our prior and current study show that this program is effective in approximately 70% of adolescent female athletes in improving the potentially harmful position of valgus lower limb alignment. This program was also previously shown to be effective in inducing changes in neuromuscular indices including decreased peak landing forces of 22%, decreased peak adduction and abduction moments of 50%, and increased hamstrings to quadriceps muscle peak torque ratios of 26% (nondominant side) and 13% (dominant side) (15). In addition, this program significantly reduced the incidence of noncontact knee ligament injuries in female high-school athletes (2,12,15).

This study focused solely on female athletes because of the gender disparity in noncontact ACL injury rates. Other investigations have reported significant differences between genders upon landing in overall lower limb alignment, knee flexion angles, knee extension moments, knee valgus moments, and ground reaction forces (7,13,15,17,19). It is important to note that the increased incidence of knee ligament injuries in female athletes is likely multifactorial, and it is currently unknown as to which factors are dominant and which play a negligible role (3). Factors inherent in women have been suggested, including a narrow intercondylar notch, smaller-sized ACL, pelvic–hip–knee–foot alignment, generalized knee laxity, foot pronation, and hormonal variations (10). Extrinsic factors related to athletic conditioning, skill, training, and equipment have also been discussed. Continued research is required to answer the question of which factors are most responsible for this injury disparity between male and female athletes.

**Practical Applications**

Adolescent female volleyball players can improve their overall lower limb alignment on a drop-jump test after 6 weeks of neuromuscular retraining designed to reduce the risk of a noncontact ACL injury. Approximately 70% of the athletes may retain their improvements in this test up to 1 year after training. The improvement in lower limb alignment is important because it reduces the potentially harmful position of valgus lower limb alignment that is commonly seen during noncontact ACL injuries. The drop-jump test is useful to coaches and trainers as a general indicator of an athlete’s ability to control lower limb alignment on landing because it uses standard equipment and a single camera and is relatively easy to perform in any facility. Athletes who do not improve on this test are encouraged to continue neuromuscular training. Further research is required to determine if this improvement is related to the reduction in ACL injury rates in trained female athletes and if a poor knee separation distance on landing from a drop-jump test is a risk indicator for a noncontact ACL injury.

**References**


Retention Improvement Neuromuscular Control Drop-Jump Test


