A Training Program to Improve Neuromuscular Indices in Female High School Volleyball Players

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ABSTRACT

Noyes, FR, Barber-Westin, SD, Smith, ST, and Campbell, T. A training program to improve neuromuscular indices in female high school volleyball players. J Strength Cond Res 25(8): 2151–2160, 2011—The purpose of this study was to determine if a sports-specific training program could improve neuromuscular indices in female high school volleyball players. We combined components from a previously published knee ligament injury prevention intervention program for jump and strength training with additional exercises and drills to improve speed, agility, overall strength, and aerobic conditioning. We hypothesized that this sports-specific training program would lead to significant improvements in neuromuscular indices in high school female volleyball players. Thirty-four athletes (age 14.5 years ± 1.0) participated in the supervised 6-week program, 3 d-wk–1 for approximately 90–120 minutes per session. The program was conducted on the school’s volleyball court and weight room facilities. The athletes underwent a video drop-jump test, multistage fitness test, vertical jump test, and sit-up test before and after training. A significant increase was found in the mean VO2max score (p < 0.001), where 73% of the athletes improved this score. A significant improvement was found in the sit-up test (p = 0.03) and in the vertical jump test (p = 0.05), where 68% of the athletes increased their scores. In the drop-jump video test, significant increases were found in both the mean absolute knee separation distance (p = 0.002) and in the mean normalized knee separation distance (p = 0.04), indicating improved lower limb alignment on landing. No athlete sustained an injury or developed an overuse syndrome during training. This program significantly improved lower limb alignment on a drop-jump test, abdominal strength, estimated maximal aerobic power, and vertical jump height and may be implemented in high school female volleyball programs.

Key Words lower limb alignment, vertical jump, VO2max

INTRODUCTION

Competitive volleyball is a demanding sport that requires speed, agility, upper and lower body strength, and maximal aerobic power. Training programs and methods have been developed and tested to improve player fitness and skills with differing results (12,14,22–24,26,35). Investigations vary widely in the populations studied, duration of training, exercises and drills selected, and outcome measures. From both a research and coaching viewpoint, there exists no gold standard for training competitive volleyball players to improve all of the factors required to enhance player performance. To date, no studies have been published that we are aware that assessed changes in neuromuscular indices in high school female players following a specific intervention program.

Of concern is the number of lower extremity injuries incurred by competitive volleyball players. Agel et al. (1) reviewed 16 years of National Collegiate Athletic Association injury surveillance data in women’s volleyball and found that the lower extremity accounted for >55% of all injuries. Knee ligament and meniscus tears represented 14% of all injuries and typically involved a noncontact mechanism. The authors recommended that future training programs include prevention efforts to decrease ankle sprains and acute traumatic knee injuries.

The effort to reduce lower extremity injuries in volleyball should include a decrease in loads placed on the lower extremity and an improvement in jumping and landing techniques (19,32). This is especially true when considering the fact that many noncontact anterior cruciate ligament (ACL) ruptures occur when an athlete lands from a jump (10,19), when ground reaction forces are 3–14 times that of body weight (28,34). Researchers have recommended that neuromuscular retraining to decrease the risk of an ACL injury should teach athletes to control the upper body, trunk, and lower body position; lower the center of gravity by increasing hip and knee flexion during landing, cutting, and decelerating; and land with smaller ground reaction forces (15,32). High-risk sports for noncontact ACL injuries and other lower extremity injuries that would benefit from this type of neuromuscular retraining include soccer, basketball, volleyball, field hockey, and alpine skiing (3,9,21,33).
Volleyball Neuromuscular Training Program

In this manner, we took into account our prior experience in training female athletes with an ACL prevention program, Sportsmetrics (18) (Cincinnati Sportsmedicine Research and Education Foundation, Cincinnati, OH, USA). This program was proven to be effective in improving neuromuscular indices in high school female basketball, soccer, and volleyball players, with investigations reporting improved overall lower limb alignment on a drop-jump test (27), increased knee flexor strength (18,27,37), increased knee flexion angles on landing (18,30), reduced abduction and adduction moments and ground reaction forces (18), and reduced incidence of noncontact ACL injuries (17). We developed a volleyball-specific program for competitive female high school players, implementing the essential components of Sportsmetrics along with other exercises designed to improve speed, agility, strength (upper extremity, lower extremity, and core) and aerobic conditioning. The additional exercises were incorporated in an effort to improve indices not previously included in knee ligament injury prevention programs and to increase player compliance with training. We hypothesized that this training program would significantly improve lower limb alignment on landing, estimated maximal aerobic power ($\dot{V}O_{2\text{max}}$), vertical jump height, and abdominal strength in high school female volleyball players. The program was designed to be conducted using high school facilities, including the volleyball court and weight training room, so that any coach or trainer could conduct training before the start of the season.

**METHODS**

**Experimental Approach to the Problem**

This study was undertaken to determine if a sports-specific training program could improve neuromuscular indices in female high school volleyball players. A program was devised which used components from a previously published knee ligament injury prevention program for jump and strength training, with exercises and drills added to improve speed, agility, overall strength, and aerobic conditioning. A battery of tests was conducted to determine the effectiveness of this training program.

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 a video drop-jump test, a multistage fitness test, a vertical jump test, and a abdominal strength (sit-up) test before the neuromuscular training program was initiated. The subjects then participated in the training program that consisted of 3 sessions per week on Mondays, Wednesday, and Fridays for 6 weeks. The sessions lasted 90–120 minutes and consisted of a dynamic warm-up, jump training, strength training, speed and agility drills specific for volleyball, and flexibility. All training sessions were supervised by certified Sportsmetrics instructors and were conducted on the school’s volleyball court and weight room facilities. Then, the subjects underwent all of the previously described tests within 1 week of conclusion of the training program in an identical manner as that done before the training program was initiated.

**Subjects**

All testing and training procedures were fully explained, and written informed parental consent was obtained for each subject. The study was approved by an Internal Review Board for use of human subjects. A total of 34 competitive female volleyball players (age 14.5 ± 1.0 years, range 14–17 years; height 167.6 ± 5 cm, range 160–178; weight 58.1 ± 8.1 kg; mean body mass index [BMI] 20.5 ± 1.9, range 17.7–24.4) from one area high school team 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 high school 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 program.

**Procedures**

**Video Drop-Jump Test.** A drop-jump video screening test was done as previously described in detail (27). A Sony Mini DV Camcorder equipped with a memory stick (Sony Products, Park Ridge, NJ, USA) with a frame rate of 29.97 frames per second was positioned in front of a box. Reflective markers were placed at the greater trochanter, the lateral malleolus, and the center of the patellae on both the right and left legs. Athletes were instructed to wear fitted, dark shorts and low-cut gym shoes. The subjects performed a drop-jump sequence by first jumping off the box, landing, and immediately performing a maximum vertical jump. No specific instruction was 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.

A research assistant viewed all 3 trials and the one that best represented the subject’s jumping ability was selected. The video was advanced frame by frame to capture the following images as still photographs: (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 movement of the arms and the body as the subjects prepared to perform the maximum vertical jump.

The captured images were imported into the hard drive of a desktop computer and digitized on the computer screen as previously described (27). The absolute centimeters of separation distance between the right and left hips, knees, and ankles was measured, and the distance between the knees and ankles was then normalized according to the hip separation distance. The data were distributed into 3 categories: ≤60% normalized knee separation distance (Figure 1), 61–80%, and >80% during the landing phase.
The reliability of the drop-jump test was reported previously in a group of 17 female volleyball, basketball, soccer, and gymnastic high school athletes (27). 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.

**Multistage Fitness Test.** \(V_\text{O}_{2}\max\) was measured using the multistage fitness test (20,31). The subjects were required to perform a shuttle run back and forth along 20 m, keeping in time with a series of signals on a compact disk by touching the appropriate end line in time with each audio signal. The frequency of the audible signals (and hence, running speed) was progressively increased until the subjects reached volitional exhaustion and could no longer maintain pace with the audio signals. \(V_\text{O}_{2}\max\) was estimated using regression equations described by Ramsbottom et al (31). Test–retest reliability of this task has been reported by others to be sufficient, with ICCs ≥ 0.90 (13,20,38). The data were also placed into gender- and age-matched percentile groups determined by the American College of Sports Medicine (11).

**Vertical Jump.** The subjects’ vertical reach was measured using a Vertec Jump Training System (Sports Imports, Columbus, OH, USA). First, the standing reach was measured. Then, a countermovement maximum jump with arm swing was performed 3 times and the highest jump obtained was recorded. Reliability for the assessment of vertical jump height using the Vertec was reported by others to be excellent, with ICCs of 0.92 (6) and 0.94 (39).

![Figure 1. The landing phases of the drop-jump video screening test. 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. Top, before training, this athlete demonstrated a 25% normalized knee separation distance. Bottom, after training, she had a markedly improved 70% normalized knee separation distance.](image-url)
**Table 1.** Sportsmetrics volleyball training program.*

<table>
<thead>
<tr>
<th>Session no.</th>
<th>Jump training</th>
<th>Agility training</th>
<th>Acceleration, speed training</th>
<th>Ladders, quick feet, reaction training</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–3</td>
<td>Wall jump (20–25 s)</td>
<td>Serpentine run (3 reps)</td>
<td>Partner push-offs (5 reps × 5 s), Sprint/backpedal (6 reps)</td>
<td>Up–up/down–down on mat (2 reps × 45 s), wheel drill/listen to instructor (2 reps × 45 s), volleyball court suicides (double suicide × 2 reps)</td>
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<tr>
<td></td>
<td>Tuck jump (20–25 s)</td>
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<td></td>
<td>Squat jump (10–20 s)</td>
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<td></td>
<td>Barrier jumps (20 s each)</td>
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<tr>
<td></td>
<td>Forward–backward</td>
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<td></td>
<td>180° jump (20–25 s)</td>
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<td></td>
<td>Broad jump (5–10 reps)</td>
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<td></td>
<td>Bounding in place (20–25 s)</td>
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<tr>
<td></td>
<td>Pattern jumps (5 reps)</td>
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<tr>
<td>4–6</td>
<td>Same as sessions 1–3</td>
<td>Modified shuttle runs (2 reps)</td>
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<tr>
<td></td>
<td>Same as sessions 1–3</td>
<td></td>
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<tr>
<td>7–9</td>
<td>Triple broad into vertical jump (5–8 reps)</td>
<td>Square drill (3 reps)</td>
<td>Mountain climbers (6 reps), ¼ Eagle into sprint–listen to instructor (6 reps)</td>
<td>Outside foot in/on ladder/mat (2 reps × 45 s), Sprint-quick feet–listen to instructor (2 reps × 30 s), Volleyball court suicides (double suicide × 2 reps)</td>
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<td></td>
<td>Barrier hops (25–30 s each)</td>
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<td></td>
<td>Side-to-side</td>
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<td></td>
<td>Forward–backward</td>
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<td></td>
<td>Single leg hop (5–8 reps)</td>
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<td></td>
<td>Scissors jump (25–30 s)</td>
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<td>Bounding for distance (1–2 runs)</td>
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<td></td>
<td>Pattern jumps (5 reps)</td>
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<td></td>
<td>Same as sessions 7–9</td>
<td>Same as sessions 7–9</td>
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<tr>
<td>10–12</td>
<td>Nebraska drill (3 reps)</td>
<td>Partner push-offs (6 reps × 5 s), Box drill–90° turns (3 reps)</td>
<td>In–in/out–out on ladder (2 reps × 45 s), reaction drill/watch instructor point (2 reps × 45 s), Volleyball court suicides (double suicide × 4 reps)</td>
<td>Ladders, quick feet Up–up/back–back on ladder (2 reps × 45 s), reaction mirror drill/partner pressing (2 reps × 60 s), Jingle–jangle (20 yd up and back × 5)</td>
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<tr>
<td></td>
<td>Same as sessions 7–9</td>
<td>Same as sessions 7–9</td>
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<tr>
<td>13–15</td>
<td>Step, jump up, down, vertical (30 s)</td>
<td>Illinois drill (4 reps)</td>
<td>Resisted sprints with band (7 reps), Sprint–180°–jog back (7 reps)</td>
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<tr>
<td></td>
<td>Mattress jumps (30 s each)</td>
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<tr>
<td></td>
<td>Side-to-side</td>
<td></td>
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<tr>
<td></td>
<td>Forward–backward</td>
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<td></td>
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<tr>
<td></td>
<td>Triple single leg hop, stick (5 reps each leg)</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>Jump into bounding (3–4 reps)</td>
<td></td>
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<tr>
<td></td>
<td>Pattern jumps (5 reps)</td>
<td></td>
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<tr>
<td>16–18</td>
<td>Same as sessions 13–15</td>
<td>T-drill/5–10–5 (4 reps)</td>
<td>Mountain climbers (7 reps), sprint–360°–jog back (7 reps)</td>
<td>Ladder 1 foot forward, 1 foot backward (2 reps × 45 s), advanced wheel drill/listen to instructor (2 reps × 60 s), Jingle–jangle (10 yd up and back × 5)</td>
</tr>
</tbody>
</table>

*Reps = repetitions; s = seconds.
Abdominal Strength. A sit-up test was conducted to measure abdominal strength (25). With the subjects lying on their back with the knees bent and feet flat on the floor (held in place by a partner) and arms folded across the chest, sit-ups were performed by raising up so that the elbows touched the knees and then lowering back down to the floor. The number of repetitions completed in 60 seconds was recorded. Other investigations have demonstrated adequate reliability of sit-up tests in normal subjects of 0.84 (reliability coefficient) and chronic pain populations of 0.77 (ICC, test–retest) and 1.0 (ICC, interrater) (16).

Neuromuscular Retraining Program. The subjects participated in a modified Sportsmetrics (Cincinnati Sportsmedicine Research and Education Foundation, Cincinnati, OH, USA) volleyball training program. The training was comprised of a dynamic warm-up, jump training, and flexibility exercises described previously (4,17,18). In addition, strength, agility, acceleration, speed, and endurance drills were added to specifically target the requirements of competitive volleyball players (see Table 1 and Figure 2). All training sessions were conducted by certified instructors; there were 3 sessions per week (on nonconsecutive days) for 6 weeks, and all were done in the afternoon upon completion of school. Each session lasted approximately 90–120 minutes and was conducted at the school’s volleyball court and weight room facilities.

The dynamic warm-up was consistent throughout all sessions and included heel–toe walking, straight leg marching, leg cradle walking, dog and bush walking, and high knee skipping for half a court. In addition, high knees and glut kicks, stride-out running and all-out sprinting were done for one full court.

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, and during decelerating and cutting. Trainers gave constant feedback on jump-land mechanics and decelerating, cutting and pivoting techniques as previously described (4,17,18). Strength training focused on hamstring, hip flexion and abduction, core, abdominal, and shoulder musculatures to aid in proper lower extremity alignment and muscle recruitment patterns. The subjects

![Figure 2. A) Forward-backward mattress jumps. B) Reaction sprint drill with instructor. C) Resisted sprint with band drill.](image-url)
performed strength training in a weight room using machines, free weights, a cable system, and body weight exercises. At the end of each session, flexibility exercises were conducted for the hamstrings, quadriceps, iliotibial band, hip flexors, gastrocnemius and soleus, deltoid, triceps, pectoralis major, biceps, and low back.

Twenty of the 34 subjects had participated in Sportsmetrics training 12 months before the initiation of this investigation. That program was different from the current program because it entailed the dynamic warm-up, jump training, and flexibility exercises; however, strength training was not conducted in the weight room, but on-the-court with the use of resistance bands and body weight exercises. In addition, fewer volleyball-specific exercises and drills were done for agility, speed, and aerobic conditioning. We compared the results of testing between the subjects who had undergone training previously and those who had not to determine if any significant differences existed which would preclude assessing the impact of the current program on all 34 subjects combined.

**Statistical Analyses**

For data that were normally distributed (Kolmogorov–Smirnov test), a 2-tailed paired *t*-test was used to detect differences between the 2 test periods. Data that failed the normality test were assessed with Wilcoxon matched-pairs signed-ranks tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Pretrain</th>
<th>Posttrain</th>
<th>Difference</th>
<th><em>p</em> Value</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multistage fitness test (VO_{2}max)†</td>
<td>39.4 ± 4.8</td>
<td>41.4 ± 4.0</td>
<td>2.2 ± 3.2</td>
<td>&lt;0.001</td>
<td>−0.45</td>
</tr>
<tr>
<td></td>
<td>(31.8–47.4</td>
<td>(32.9–49.3)</td>
<td>(−8.1 to 6.6)</td>
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</tr>
<tr>
<td>Abdominal strength (reps)*</td>
<td>37.7 ± 5.3</td>
<td>40.5 ± 5.0</td>
<td>2.7 ± 4.8</td>
<td>0.03</td>
<td>−0.50</td>
</tr>
<tr>
<td></td>
<td>(30–50)</td>
<td>(31–55)</td>
<td>(−12 to 5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cl: 35–40</td>
<td>Cl: 38–43</td>
<td></td>
<td></td>
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<tr>
<td>Vertical jump (cm)</td>
<td>40.1 ± 7.1</td>
<td>41.5 ± 4.5</td>
<td>1.2 ± 5.2</td>
<td>0.05</td>
<td>−0.24</td>
</tr>
<tr>
<td></td>
<td>(31.8–63.5)</td>
<td>(33–52)</td>
<td>(−10 to 17.8)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Cl: 37.5–42.7</td>
<td>Cl: 39.8–43.1</td>
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<tr>
<td>Drop-jump test</td>
<td>21.1 ± 8.2</td>
<td>25.9 ± 5.2</td>
<td>4.7 ± 7.7</td>
<td>0.002</td>
<td>−0.70</td>
</tr>
<tr>
<td></td>
<td>(8.9–42)</td>
<td>(16.9–41.2)</td>
<td>(−21.5 to 9.5)</td>
<td></td>
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<tr>
<td></td>
<td>Cl: 18.2–24.2</td>
<td>Cl: 24.1–27.8</td>
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<tr>
<td>Normalized knee separation distance (%)</td>
<td>56.3 ± 19.1</td>
<td>63.3 ± 12.7</td>
<td>6.9 ± 18.2</td>
<td>0.04</td>
<td>−0.43</td>
</tr>
<tr>
<td></td>
<td>(25.6–109.9)</td>
<td>(42.7–98.3)</td>
<td>(−51.3 to 25.4)</td>
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<tr>
<td></td>
<td>Cl: 49.3–63.3</td>
<td>Cl: 58.8–67.8</td>
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</tbody>
</table>

*Mean ± SD, range, 95% confidence intervals.
†ml/kg/min.

Figure 3. In the multistaged fitness test, a significant difference was found in the distribution of athletes in the gender- and age-matched percentile groups before and after training (*p* = 0.01).
Chi-square analyses were used to compare the distribution of subjects in the percentile rank subcategories before and after training in the multistage fitness test and in the 3 categories ($\leq 60$, $61-80$, and $>80\%$) in the drop-jump test. Unpaired $t$-tests were used to assess differences in the outcome of each test between subjects who attended at least 15 training sessions and subjects who attended <15 sessions. Effect sizes were calculated and interpreted according to Cohen’s standards (7). For all comparisons, a level of $p \leq 0.05$ was considered to be statistically significant.

**RESULTS**

No subject sustained an injury that resulted in loss of time training or that required formal medical attention. There was no significant change in mean height, weight, or BMI at the posttraining test.

There were no statistically significant differences between the 20 subjects who had undergone Sportsmetrics training previously and the 14 subjects who had not undergone such training in the multistage fitness test, the vertical jump, and the abdominal strength test before and after the current training program. There was a significant difference in the drop-jump test before the investigation began, because those who had undergone training previously had greater normalized knee separation distance values ($63 \pm 18$ and $49 \pm 18$, respectively, $p = 0.04$) and absolute cm of knee separation distance ($24 \pm 8$ and $18 \pm 8$ cm, respectively, $p = 0.04$). All of the subjects who had not undergone training had $<60\%$ normalized knee separation distance, representing poor lower limb control and alignment, compared to 47% of the subjects who had undergone training previously. However, there was no difference between these groups after training in either the normalized or absolute centimeters of knee separation distance.

The mean number of training sessions attended was $15.3 \pm 1.4$. Twenty-one subjects (62%) attended $\geq 15$ sessions, while 13 (38%) attended $11-14$ sessions. There was no statistically significant difference in any of the tests conducted after training between the group of subjects who attended $\geq 15$ sessions and those who attended $<15$ sessions.

A statistically significant improvement was found in the mean $V_{O_{2}}$ max score (see Table 2, $p < 0.001$) and in the difference in the distribution of subjects in the percentile rank subcategories between pretrain and posttrain test sessions ($p = 0.01$, Figure 3). Seventy-three percent of the subjects improved this score. A significant improvement was found in the sit-up test ($p = 0.03$) and in the vertical jump test ($p = 0.05$), because 68% of the subjects increased their scores. In the drop-jump video test, significant increases were found in both the mean absolute knee separation distance ($p = 0.002$) and in the mean normalized knee separation distance ($p = 0.04$) on landing. There was no significant difference in the distribution of subjects in the normalized knee separation distance categories between test sessions (Figure 4). Overall, 25 of the subjects (74%) improved on all tests, 5 subjects improved on 3 of the 4 tests, and 4 subjects improved on 2 tests.

Seven of the 14 subjects (50%) who had not participated in Sportsmetrics training previously demonstrated at least 60% normalized knee separation distance on landing. Eighteen of the 20 subjects who had undergone Sportsmetrics training previously either improved or retained $>60\%$ normalized knee separation distance on landing.

**DISCUSSION**

This represents the first study to our knowledge to determine the effects of a neuromuscular retraining program designed specifically for female high school volleyball players. We used a training program previously proven in female athletes to improve overall lower limb alignment on a drop-jump test (27), increase knee flexor strength (18,27,37), increase knee flexion angles on landing (18,30), reduce potentially harmful abduction and adduction moments and ground reaction forces (18), and reduce the incidence of noncontact ACL injuries as the...
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basis for this study (17). To provide athletes with a comprehensive program that also focused on agility, speed, and endurance, other exercises and drills were added. Training was done on the volleyball court with no expensive or special equipment required. Weight training was accomplished in the high school's weight room. We have found that this type of training is more easily managed, with better athlete compliance, if the sessions are conducted at the players' school or athletic facility. In addition, we strongly promote the importance of testing specific neuromuscular indices before and after training. This allows not only the quantification of the program's effectiveness, but promotes further education and communication between athletes, parents, and coaches. Athletes who fail to improve may require further neuromuscular training or advanced instruction on the specific task by either a certified trainer or volleyball coach. For instance, Gabbett (14) reported that junior volleyball players who underwent instructional-based training had greater spiking accuracy, setting accuracy, passing accuracy, and passing technique compared to players who completed a skill-based conditioning program. It is important to note that skill-based training alone does not improve physiological or anthropometric characteristics of players (12).

One potential limitation of this study is the inclusion of 20 subjects who had undergone Sportsmetrics training 12 months before this investigation began. However, when compared to the 14 subjects who had not participated in any prior training program, the only significant differences found were in the normalized and absolute cm of knee separation distance on landing before training was initiated. This represents a retention effect of the jump training instruction, which is the topic of a separation investigation (5). Approximately one-half of the subjects had retained a more neutrally aligned lower limb position during this task between training programs. This is compared to 100% of the subjects who had not participated in a training program that demonstrated <60% normalized knee separation distance on landing, indicating poor (valgus) overall lower limb alignment. There was no difference between these groups of subjects in the mean values in the drop-jump test after training, or in any of the other tests before or after training. We therefore felt it was valid to assess the group as a whole in evaluating the effects of the current training program. A second limitation to this study was no control or comparison group, which will be included in future studies.

The drop-jump video test provides a general indicator of an athlete's lower limb axial alignment in the coronal plane. We agree with others who have noted that this type of test cannot be used as a risk indicator for noncontact knee ligament injuries (29). This is because this video test performed during one maneuver only shows the position of the hips, knee and ankles in a single plane, whereas noncontact ACL injuries frequently occur in side-to-side, cutting, or multiple complex motions. However, our test provides a general assessment of lower limb position and clearly depicts athletes who have poor control on landing. In this study, each of the 14 athletes who had not undergone training previously had ≤60% normalized knee separation distance on landing. In a prior investigation (27), 77% of 325 untrained female athletes had the same result, indicating poor overall lower limb alignment. In that investigation, the percentage decreased to 34% upon completion of Sportsmetrics training. Athletes who are unable to obtain at least 60% normalized knee separation distance after training are encouraged to continue neuromuscular and strength training if possible within the allowance of their sport training and season participation.

We found in the multistage fitness test, 44% of the subjects were either in the average (16%) or below average (28%) categories before training. After training, only 15% remained in these categories and therefore, the program appeared effective in improving estimated maximal aerobic power. The multistage fitness test has been used by others to determine cardiovascular fitness levels of children in multiple countries aged 6–19 years (36), junior rugby league players (13), and youth soccer players (38) and is recommended by the American College of Sports Medicine (11) as a valid and reliable method to determine VO2max. This is a cost-effective and simple method, requiring only a commercially available compact disc and 2 cones for the shuttle run which is advantageous when laboratory and treadmill equipment and personnel are not available. Improvements were found in 73% of the subjects in our study. There were 4 subjects who had poorer results at the posttraining test and 5 who failed to improve for unknown reasons.

Improvements were found in 68% of the subjects for the abdominal strength and vertical jump tests. The improvements in the abdominal strength test ranged from 2 to 9 more sit-ups performed in the 60-second time period. The increases in vertical jump height in those subjects that improved ranged from 3 to 24 cm (mean 10.4 cm). Seven subjects had poorer results, ranging from −3 to −28 cm (mean −9.9 cm). Athletes that do not improve their vertical jump height may benefit from more intensive training designed specifically for this task, including instruction on technique and differing plyometric exercises than those used in this program. A recent meta-analysis of the effects of plyometrics on improving vertical jump height concluded that a combination of squat, countermovement, and depth jumps was significantly more effective than the use of a single plyometric exercise (p < 0.05) (8). The overall enhancement in vertical jump height after training in this meta-analysis was 3.90 cm, or approximately 7%. Our future studies will assess if such a program, done in athletes who failed to improve after the 6-week training program described in this study, will increase vertical jump height. Advanced plyometric training does carry the risk of injury, so caution is warranted and supervision required to ensure the athlete performs the exercises safely and correctly.

In conclusion, this neuromuscular training program significantly improved lower limb axial alignment on a drop-jump
test, abdominal strength, estimated maximal aerobic power, and vertical jump height in high school female volleyball players. Future studies are required to determine if this program also reduces the incidence of noncontact ACL injuries during volleyball practice and competition. In addition, it remains to be determined if the improvements in these indices translate into improved player performance during competition.

**Practical Applications**

The findings of this study indicate the effectiveness of a new volleyball training program in female high school athletes. The program combines components from a previously published knee injury prevention program for jump and strength training with other exercises and drills to improve speed, agility, overall strength, and aerobic conditioning. All training was done on a high school volleyball court and weight room. Athletes demonstrated significant improvements in lower limb alignment on a drop-jump test, abdominal strength, estimated maximal aerobic power, and vertical jump height. The subjects were experienced, competitive volleyball players, and it is unknown whether these results will apply to less-experienced players. We recommend that coaches and trainers who wish to implement this program conduct the tests that were done in this study to determine the program’s overall effectiveness. Athletes who fail to improve should be encouraged to continue neuromuscular training. This program is designed to be conducted just before the beginning of the high school volleyball season.

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