The Effect of Strength Training on the Jump-Landing Biomechanics of Young Female Athletes: Results of a Randomized Controlled Trial

Joanne L. Parsons, PhD, Richard Sylvester, MSc, and Michelle M. Porter, PhD

Objective: To investigate the effect of leg-focused strength training on the jump-landing mechanics of young female athletes.

Design: Single-blind, randomized controlled clinical trial.

Setting: University-based training program.

Participants: Forty female athletes, 10 to 14 years old, were randomly allocated to intervention or active control.

Interventions: Twice weekly training was performed by the leg strengthening group [intervention group (IG); n = 19] and the active control group (CG; n = 17), for 12 weeks. Control group participants performed upper body strengthening exercises.

Main Outcome Measure: Jump-landing performance was assessed by a blinded observer using the Landing Error Scoring System (LESS).

Results: There was no difference between the IG and CG postintervention (IG mean LESS score 6.0 ± SD 1.8 vs CG mean 6.1 ± SD 1.8; P = 0.85).

Conclusions: Strength training of the legs does not seem to improve jump-landing abilities in young female athletes compared with active controls who strengthened their arms.

Clinical Relevance: Leg strengthening may not provide an advantage over arm strengthening for improving jump-landing movement patterns in young female athletes. This has implications for the design of conditioning programs if injury prevention is a goal.

Key Words: injury prevention, neuromuscular training, ACL, knee

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and agility exercises, found that young athletes decreased the amount of knee valgus or overall LESS score demonstrated during a jump landing. However, one study failed to find a decrease in knee valgus after an intervention. The age at which training is introduced is significant, as the results of a meta-analysis found that participation at a younger age (less than 18 years) provides a protective effect for ACL injury. However, the youngest participants included in that review were 14 years of age. We are only aware of one study that included athletes younger than 14 years. That study of 12-year old to 17-year-old girls indeed found that the intervention group (IG) experienced a 64% decrease in ACL injuries compared with the control group (CG). Because the intervention consisted of balance and core stability training, feedback on knee position and leg strengthening, it is impossible to identify the contribution of each individual exercise to decreasing injury risk. This would be valuable information to coaches and athletes to optimize time. Large study populations are required to investigate the influences of neuromuscular training on ACL injury rates directly; therefore, it may be an efficient use of resources to study the individual effect of exercise types on known injury mechanisms, such as landing from a jump.

Because ACL injury rates rise considerably in the mid-teens, it is surprising more studies that aim to explore the effect of training programs on injury mechanics, as well as ACL injury rates, have not included younger participants. To date, no studies have investigated the contribution of the different components of training programs to improving movement patterns in a young population, although previous work has shown resistance training in children can positively affect functional movement. It would seem logical to examine the effectiveness of prevention programs at an earlier age, before the chance of injury increases. Therefore, the purpose of this study was to investigate whether lower-body strength training would change the movement patterns exhibited by young female athletes aged 10 to 14 years during a jump landing. We hypothesized that lower-body strength training would result in a significantly lower LESS score compared with an active CG after 12 weeks of training.

**METHODS**

**Participants**

Athletes from local sport organizations were recruited through posters placed in university and city fitness facilities, as well as website and e-mail notifications from sport administrators. Participants were required to be 10 to 14 years old at the time of baseline testing and have at least 1 year of participation in organized sports involving jumping or cutting. Girls were excluded if they had engaged in resistance training in the last 6 months, had any health condition or injury that would affect participation in testing or training, or had musculoskeletal pain with a rating of more than 3 out of 10 on a visual analog scale.

**Procedures**

Each athlete attended a pretest and posttest session conducted by the same blinded assessor. The athlete warmed up by walking on a treadmill for 5 minutes before having her jump-landing mechanics evaluated. The LESS consists of 17 characteristics that may be observed during a jump landing. A lower LESS score indicates better landing mechanics, with a score of >6 suggestive of “poor” technique. Intra-rater reliability of the LESS has been established in adult (intraclass correlation coefficient [ICC] = 0.90) and high school (ICC = 0.97) populations. According to protocol, the athlete jumped forward off a 30-cm high box to a horizontal distance of 50% of her height, landed on 2 feet, and immediately jumped straight up as high as she could before landing again. The task was videotaped by 2 video cameras, capturing the sagittal plane and the frontal plane. The athlete completed 3 jumps; if the athlete did not land in the designated area or the movement was not smooth and continuous, the athlete was asked to repeat the jump. To complete the test session, the girls underwent grip strength, push-up, and vertical jump testing. These measures were used as indicators of the effect of the 12-week resistance training program on muscle strength and power.

At the end of the first test session, the athlete chose an opaque envelope and gave it to the assessor. The envelopes contained a paper designating the athlete into either the IG or placebo CG. The assessor did not open the envelope but passed it on to the principal researcher. The athlete was then contacted within 1 to 2 days, told which group she was in, and the first training session was scheduled. Athletes were randomized in blocks of 4 to ensure equal numbers in each of the 2 groups.

**Intervention**

The girls trained twice per week for 12 weeks, for an hour each time using free weights or body weight, with at least 1 rest day in between. During the study, the athletes, with the help of their parents, recorded how many minutes they participated in organized sports activities. All training sessions were conducted by 1 of 2 trainers (a physical therapist or a certified personal trainer) in a private room at the University. The supervision ratio was a maximum of 2 athletes to 1 trainer. At the start of each training session, the girls warmed up for about 5 minutes with dynamic exercises such as jogging, skipping, and side shuffles. Girls in the 2 groups were scheduled at different times to avoid cross-contamination.

The first 3 sessions were used for familiarization to the exercises and to weight-training in general. Light resistance was used, if any. The athletes were taught to execute the movements correctly and safely. At the fourth training session, and again at the last training session, a 10 repetition maximum (RM) test was performed for squats and lunges in the IG and chest press and bicep curls in the CG. This was undertaken to determine the starting load for the strength training program and provide feedback to the participants about their improvements over the 12-week program. A maximum weight of 6RM is recommended for children to lift and as the athlete would be doing 10 to 15 repetitions throughout the program, a 10RM was chosen as a safe, practical test. Training loads were then calculated as follows: first set—50% of 10RM; second set—75% of 10RM; and third set—100% of 10RM. Over the twelve weeks, as soon as the
athlete could complete 15 repetitions of her 10RM weight, the resistance was increased 10% to 20% at the next training session and the repetitions decreased back to ten.

Exercises for the IG included squats, lunges, side-lying leg lifts with an ankle weight, and supine hamstring curls on a pillowcase, progressing to a ball.31 These exercises were chosen to ensure that the major muscle groups that act to decelerate and control the landing movement would be targeted.32 They completed 3 sets of 10 to 15 repetitions of squats and lunges, followed by 2 sets of 10 to 15 repetitions of the leg lifts and hamstring curls. One athlete in the leg group could not do lunges without discomfort and therefore did step-ups as a replacement.

Rather than including a CG who received no attention, we chose to include a placebo CG who undertook arm training. The inclusion of an active CG was intended to account for the personal interaction received by the IG, because there is suggestion that some of the positive effects of exercise may be due to the perception an individual has of exercise, rather than the actual completion of the exercise itself.33,34 Because arm strength was not anticipated to contribute significantly to landing technique, we chose arm focused exercises for the CG. Exercises consisted of chest press, bicep curls, shoulder press, and bench rows. The girls completed 3 sets of 10 to 15 repetitions of chest press and bicep curls, and 2 sets of 10 to 15 repetitions of shoulder press and bench rows. Three athletes were unable to do shoulder press without shoulder discomfort; bench triceps extensions were substituted instead.

Outcome Measures
A priori it was determined that the LESS score would be the primary outcome variable. The LESS was scored from randomly ordered videos after all data for all participants were collected. The first landing of the jump sequence was given a LESS score by a blinded, independent assessor following the guidelines provided by the creators of the test.27 The mean of the score of the 3 jumps was used in analyses. Mean grip strength and vertical jump height, number of push-ups and 10RM scores were also calculated and used to illustrate the effects of strength training.

Analysis
Descriptive statistics were calculated for group characteristics (Table 1). IBM SPSS Statistics (Version 20; IBM Corporation, Somers, NY) was used to run an analysis of covariance (ANCOVA) to compare LESS score between the IG and CG after 12 weeks of training, using baseline LESS score as a covariate. Significance level was set at $P \leq 0.05$. This type of analysis, with the inclusion of baseline measurement as a covariate, is the most powerful method of analyzing pre/post intervention studies with a continuous outcome.35 Sample size was calculated based on a posttest difference between groups of 2 (SD = 2) and a correlation between baseline and posttraining LESS score of 0.2, as baseline LESS score was used as the covariate in analysis. Thirty-four participants were required for sufficient statistical power. To allow for drop-outs, 40 athletes who met the inclusion criteria and agreed to participate were enrolled in the study (Figure 1). An ANCOVA and a paired $t$ test were used in post hoc exploratory analyses of a subset of participants with higher (poorer) initial LESS scores to determine whether landing patterns improved with training. Paired $t$ tests and repeated measures analyses of variance were used with the secondary variables (grip strength, push-ups, and vertical jump) to explore changes in strength and performance with training.

Ethical Considerations
Ethics approval was received from the University Research Ethics Board to conduct this study. Before participation, athletes and their parents read and signed informed consent documents.

RESULTS
Thirty-six girls completed the study and their data were used in statistical analyses to address the primary hypothesis (Figure 1). Two athletes experienced injuries outside the study that may have affected their performance on posttesting. One girl sprained her ankle 3 weeks before posttesting, and another had a suspected wrist fracture and wore a cast at posttesting. Differences in posttesting LESS scores between groups were analyzed with and without these girls; excluding them did not change the results, so we have included them in the final results.

The mean and SDs for LESS score for the groups at pre and posttesting are presented in Table 2. Contrary to our hypothesis, there was no significant difference between the IG and CG in terms of LESS score after the 12-week program ($P = 0.85$). We found a strong and significant correlation between baseline LESS score and change in LESS score after the intervention (Figure 2), justifying the use of baseline LESS as a covariate. We performed secondary analyses including only those athletes who demonstrated a baseline

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**TABLE 1. Participant Characteristics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group</th>
<th>Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at baseline, yrs</td>
<td>IG</td>
<td>12.5 (1.4)</td>
<td>10.1-14.3</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>12.0 (1.3)</td>
<td>10.1-14.8</td>
</tr>
<tr>
<td>Height at baseline, cm</td>
<td>IG</td>
<td>156.9 (11.6)</td>
<td>138.5-178.0</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>156.4 (10.6)</td>
<td>135.5-177.5</td>
</tr>
<tr>
<td>Mass at baseline, kg</td>
<td>IG</td>
<td>50.8 (15.7)</td>
<td>31-87</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>51.5 (12.2)</td>
<td>32-74</td>
</tr>
<tr>
<td>Pubertal maturation observational scale at baseline</td>
<td>IG</td>
<td>5.2 (2.2)</td>
<td>2-8</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>5.4 (2.2)</td>
<td>1-8</td>
</tr>
<tr>
<td>Participation in organized sport, yrs</td>
<td>IG</td>
<td>7.6 (2.0)</td>
<td>3-11</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>6.1 (2.1)</td>
<td>3-10</td>
</tr>
<tr>
<td>Physical activity during study period (self-reported minutes)</td>
<td>IG</td>
<td>3228.4 (2134.6)</td>
<td>0-9945</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>2784.7 (1525.6)</td>
<td>0-6300</td>
</tr>
<tr>
<td>Number of training sessions attended</td>
<td>IG</td>
<td>19.7 (2.1)</td>
<td>15-24</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>19.8 (2.7)</td>
<td>15-24</td>
</tr>
</tbody>
</table>
LESS score of >6 (ie, those with poor landing ability)\textsuperscript{27}; no significant differences were found between groups ($P = 0.4$). We explored further and found that girls with a baseline LESS score of >6 significantly improved their LESS score after 12 weeks of training, regardless of group (Table 2). Some of the results of our secondary strength and performance analyses can be found in Table 3. After 12 weeks of training, left grip strength increased and the girls completed 3 to 5 additional push-up repetitions. With 10RM testing, the IG increased squat strength by 78\% (n = 14) and lunge strength by 64\% (n = 13) after 12 weeks of training. The CG increased 31\% and 35\% for chest press (n = 15) and biceps curl (n = 15) strength, respectively.

**DISCUSSION**

The results of this study failed to support our hypothesis that a 12-week leg-focused strength training program would decrease LESS score compared with a placebo CG. However, as far as we are aware, it is the first study to explore the individual contribution of strength training to improving landing patterns in a young, athletic, female population, and therefore has clinical value.

In a previous study of adolescent athletes, the improvement in LESS score after an exercise intervention, including plyometrics, flexibility, and strength training depended on the participant’s initial baseline LESS score.\textsuperscript{21} Those with higher (worse) LESS scores to begin with experienced the greatest improvement in landing mechanics. Considering that our female athletes possessed a high mean baseline LESS score and a relatively low baseline strength level when compared with adolescent or adult athletes,\textsuperscript{36} we were optimistic that our hypothesis would be supported, as the girls had more room for improvement. However, that was not the case, because no differences between groups were detected.

**TABLE 2. LESS Scores**

<table>
<thead>
<tr>
<th>Group</th>
<th>Baseline</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>IG (n = 19)</td>
<td>6.8 (1.5)</td>
<td>6.0 (1.8)</td>
</tr>
<tr>
<td>CG (n = 17)</td>
<td>6.4 (1.6)</td>
<td>6.1 (1.8)</td>
</tr>
<tr>
<td>Groups combined; baseline LESS &gt;6 (n = 22)</td>
<td>7.6 (0.9)</td>
<td>6.5 (1.0)*</td>
</tr>
</tbody>
</table>

Values are reported as means (SD).
*Posttest values different than baseline values, $P \leq 0.0001$.

**FIGURE 1. CONSORT flowchart.**

**FIGURE 2. Correlation between change in LESS score and baseline LESS score for the group as a whole. A negative change in LESS denotes an improvement in landing mechanics. $r = -0.60; P = 0.0001$.**
improvement in LESS score in the subsample with the poorest scores, regardless of group, was due to strength training. However, our primary goal was to determine whether leg-specific strengthening would improve landing mechanics and hence the inclusion of a placebo CG was deemed important to that goal.

Future work on improving landing mechanics should involve younger populations of athletes and consider baseline LESS score as a contributing factor to change scores. The effect of a whole-body strength training program in a young, female population needs to be investigated, as it seems that strengthening the lower body only does not improve LESS score.

**CONCLUSIONS**

This study is the first randomized controlled trial to investigate the effect of strength training on landing mechanics in young female athletes. Using blinded assessors, we found that lower body strength training did not improve LESS score compared with an active CG. Secondary analyses suggest that strength training in general may contribute to an improvement in landing mechanics in a subset with poorer baseline scores, however, further research is needed to confirm this.

**ACKNOWLEDGMENTS**

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**REFERENCES**


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**TABLE 3. Strength and Performance Changes**

<table>
<thead>
<tr>
<th>Test</th>
<th>Group</th>
<th>Baseline</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right grip strength, kg</td>
<td>IG</td>
<td>23.2 (6.9)</td>
<td>23.9 (6.5)</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>23.1 (6.2)</td>
<td>23.7 (5.9)</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>23.2 (6.5)</td>
<td>23.8 (6.2)</td>
</tr>
<tr>
<td>Left grip strength, kg</td>
<td>IG</td>
<td>21.1 (6.1)</td>
<td>22.2 (6.1)*</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>21.0 (6.6)</td>
<td>21.6 (6.6) *</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>21.1 (6.3)</td>
<td>21.9 (6.3) *</td>
</tr>
<tr>
<td>Push-ups</td>
<td>IG</td>
<td>8.4 (6.7)</td>
<td>11.6 (7.0)*</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>6.3 (4.6)</td>
<td>11.5 (6.2)*</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>7.6 (5.9)</td>
<td>11.6 (6.5)*</td>
</tr>
<tr>
<td>Vertical jump without arms, cm</td>
<td>IG</td>
<td>32.8 (4.7)</td>
<td>32.6 (4.4)</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>32.4 (4.8)</td>
<td>32.1 (5.0)</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>32.5 (4.7)</td>
<td>32.4 (4.6)</td>
</tr>
<tr>
<td>Vertical jump with arms, cm</td>
<td>IG</td>
<td>40.6 (6.3)</td>
<td>41.1 (5.6)</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>38.3 (5.6)</td>
<td>39.0 (6.7)</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>39.5 (5.9)</td>
<td>40.1 (6.1)</td>
</tr>
</tbody>
</table>

Values are reported as means (SD).
*Posttest values different than baseline values, *P* ≤ 0.05.

although the training stimulus was sufficient to increase strength. Our 10RM results are in accordance with existing literature that reports a 30% increase in strength is generally expected from a resistance training program of less than 20 weeks duration.36

We decided to further investigate the role of baseline LESS score in our study by considering the groups together. When we excluded those individuals with a baseline LESS score of ≥6, we did indeed see a change after training, regardless of group. These findings conflict with those of a recent study of predominantly adult men, which found that whole-body resistance training did not result in a decreased LESS score.18 Interestingly, change in stature, mass, or Pubertal Maturation Observational Scale score were not significantly associated with LESS change score in our study and therefore may be ruled out as contributors to the improvement in landing in the subsample.

One confounding factor affecting our results may be the indirect exposure of both groups to a core stability training stimulus, as some evidence links trunk muscle activation to movements in the lower extremities.37 Although no specific core strengthening exercises were given to either group, a training stimulus for those muscle groups may have existed just because of the nature of the prescribed exercises. Studies that have included core strengthening as a component of the program have found changes to jump-landing mechanics after training.10,12 However, because other types of training (eg, plyometrics) were involved in these studies, it is impossible to determine the influence of the core strength exercises on their own. We found one small study that attempted to elucidate the individual contributions of core and plyometric training. Those authors found that knee flexion during landing actually deteriorated in a group of high school female athletes in response to a 4-week core strengthening intervention.

The primary limitation of our study is the exclusion of an inactive CG. This limits our ability to conclude that the


