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Landing Technique and Performance in Youth Athletes After a Single Injury-Prevention Program Session

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Context: Injury-prevention programs (IPPs) performed as season-long warm-ups improve injury rates, performance outcomes, and jump-landing technique. However, concerns regarding program adoption exist. Identifying the acute benefits of using an IPP compared with other warm-ups may encourage IPP adoption.

Objective: To examine the immediate effects of 3 warm-up protocols (IPP, static warm-up [SWU], or dynamic warm-up [DWU]) on jump-landing technique and performance measures in youth athletes.

Design: Randomized controlled clinical trial.

Setting: Gymnasiums.

Patients or Other Participants: Sixty male and 29 female athletes (age = 13 ± 2 years, height = 162.8 ± 12.6 cm, mass = 37.1 ± 13.5 kg) volunteered to participate in a single session.

Intervention(s): Participants were stratified by age, sex, and sport and then were randomized into 1 protocol: IPP, SWU, or DWU. The IPP consisted of dynamic flexibility, strengthening, plyometric, and balance exercises and emphasized proper technique. The SWU consisted of jogging and lower extremity static stretching. The DWU consisted of dynamic lower extremity flexibility exercises. Participants were assessed for landing technique and performance measures immediately before (PRE) and after (POST) completing their warm-ups.

Main Outcome Measure(s): One rater graded each jump-landing trial using the Landing Error Scoring System. Participants performed a vertical jump, long jump, shuttle run, and jump-landing task in randomized order. The averages of all jump-landing trials and performance variables were used to calculate 1 composite score for each variable at PRE and POST. Change scores were calculated (POST − PRE) for all measures. Separate 1-way (group) analyses of variance were conducted for each dependent variable ($\alpha < .05$).

Results: No differences were observed among groups for any performance measures ($P > .05$). The Landing Error Scoring System scores improved after the IPP (change = −0.40 ± 1.24 errors) compared with the DWU (0.27 ± 1.09 errors) and SWU (0.43 ± 1.35 errors; $P = .04$).

Conclusions: An IPP did not impair sport performance and may have reduced injury risk, which supports the use of these programs before sport activity.

Key Words: injury risk, knee, anterior cruciate ligament

Key Points

- The injury-prevention program (IPP) demonstrated acute improvements in jump-landing technique.
- The IPP did not negatively affect performance variables, indicating that IPPs are as effective as a dynamic warm-up for preparing athletes for competition.
- The youth athletes could take generalized cues and immediately translate them into a sport-specific movement task, theoretically reducing the risk of lower extremity injury.

An estimated 40 million children aged 6 to 18 years participate annually in at least 1 organized sport,[1] resulting in more than 4 million musculoskeletal injuries.[2] These injuries are associated with negative consequences,[3] such as the early development of osteoarthritis,[4–6] a decreased level of physical activity,[7] and an increased rate of reinjury.[4,8,9] Therefore, injury-prevention efforts at the youth level clearly need to be increased.

Neuromuscular injury-prevention programs (IPPs) can decrease injury rates[10,11] and improve movement-based risk factors.[12–14] Poor movement technique during sport-specific activity results in abnormal joint loading and is associated with lower extremity injury risk.[11,15–18] Examples of poor movement technique include stiff landings with limited sagittal-plane lower extremity motion, excessive hip adduction and knee frontal-plane motion (ie, knee valgus, medial knee displacement), and increased hip and knee rotation.[12,13,19–21] Targeting youth athletes for neuromuscular IPPs may enable athletes to develop proper motor control prior to and throughout maturation before the ages associated with highest injury risk.

Earlier intervention may also help youth athletes grow accustomed to the routine of IPPs, which may result in better long-term compliance.[15] Soligard et al[22] observed that athletes with the highest rate of program compliance had the corresponding lowest rate of injury. However, even though the involved coaches acknowledged that injury prevention was important, compliance rates decreased as the season progressed. Therefore, it is necessary to be aware of potential barriers to injury-prevention compliance to assess the most effective way to encourage neuromuscular IPP implementation. Injury-prevention programs that are the length of a normal warm-up routine can be used before every athletic exposure to avoid taking time away

Table 1. Group Demographics

Group	No.	Mean ± SD		
		Age, y	Height, cm	Mass, kg
Injury-prevention program	27	13 ± 2	162.92 ± 10.49	57.18 ± 14.69
Static warm-up	32	13 ± 1	160.73 ± 14.76	54.27 ± 12.95
Dynamic warm-up	30	13 ± 2	161.90 ± 12.14	57.52 ± 12.91
Total	89	13 ± 2	161.57 ± 12.57	56.14 ± 13.46

from practice beyond the designated warm-up period that is relatively standard across all levels of competition and ages.[23–26]

Further examination of player attitudes toward IPPs has shown that athletes need incentives and would prefer to invest in a program that not only reduces injury but also enhances competitive performance.[22,27] In a recent study, Aguilar et al[28] indicated that a dynamic warm-up (DWU) may elicit greater strength and flexibility gains than a static warm-up (SWU). Furthermore, Faigenbaum et al[29] observed that SWUs may be suboptimal for the youth population, as they hinder power performance and flexibility. Neuromuscular IPPs are a combination of dynamic flexibility, plyometrics, and balance exercises. Therefore, an IPP may be the most advantageous option for an athletic warm-up that improves sport performance while decreasing injury risk.

To our knowledge, researchers have investigated IPP effects after a season-long program implementation, but none have compared the acute effects of an IPP on performance and movement technique with an SWU or DWU. Results that show an immediate injury-risk reduction and performance benefit by improving movement technique when using an IPP will support the recommendation to use an IPP in place of a more traditional warm-up program. This information may greatly assist neuromuscular IPP compliance and adoption in youth sports, where a high demand for performance enhancement exists. Therefore, the primary purpose of this study was to examine the immediate effects of an IPP warm-up on movement-based risk factors during a standardized jump-landing task using the Landing Error Scoring System (LESS). The total score on the LESS predicts lower extremity injury in youth athletes,[30] and the individual items on the LESS have been validated against specific movements that influence injury risk.[31] The secondary purpose was to evaluate the acute effects of an IPP warm-up on performance measures in youth athletes compared with SWU and DWU programs.

METHODS

Participants

A sample of 89 active children (60 boys, 29 girls; age = 13 ± 2 years, height = 161.57 cm ± 12.57 cm, mass = 56.14 kg ± 13.46 kg; Table 1) from a local junior boarding school and high school volunteered to participate in this study. All participants were in grades 5 to 9, were members of a school fall (soccer, dodge ball, cross-country, football) or winter (basketball) sport team and trained at least 3 days per week. Participants with self-reported injuries or illnesses that prevented them from being physically active at the time of testing were excluded from this study. All participants and their legal guardians provided written informed assent and consent, respectively, and the study was approved by the University of Connecticut–Storrs Institutional Review Board.

Procedures

Participants volunteered to complete one 30- to 45-minute test session. All test sessions took place directly after the academic school day (midafternoon) in a school gymnasium with basketball-court flooring. Participants were stratified by grade, sex, and sport and then randomized into 1 of 3 warm-up programs: IPP, SWU, or DWU (Table 1). Each participant performed a vertical jump, long jump, shuttle run, and jump-landing task in a randomized order before (PRE) and within 10 minutes after (POST) completing a 10- to 12-minute standardized warm-up protocol (Figure 1). Participants were blinded to which warm-up was the IPP.

Warm-Up Interventions

Different research assistants implemented each of the 3 warm-up protocols for all participants and were blinded to the implementation of the other protocols. All 3 protocols required 10 to 12 minutes to complete (Tables 2 through 4). The SWU protocol focused on lower extremity muscle lengthening for the hamstrings, quadriceps, gastrocnemius and soleus complex, hip flexors, and hip adductors. Participants jogged at a comfortable pace for 5 minutes and then performed 5 static bilateral stretches. Each stretch was maintained for approximately 30 seconds at a point of mild discomfort. This program was developed from previous studies in which Faigenbaum et al[29] evaluated an SWU protocol with youth athletes.

The DWU protocol focused on a gradual increase in warm-up intensity, as well as dynamic movements that mimicked actual game play (ie, shuffling and back pedaling). It was divided into 3 phases: a dynamic movement for 10 m (dynamic stretching and agility exercises), an acceleration run for 10 m, and a recovery jog back to the starting line. Cones placed 10 and 20 m from the starting line signified the phase transitions. The DWU involved dynamic-flexibility exercises for the hamstrings, quadriceps, gastrocnemius and soleus complex, hip flexors, hip adductors, and gluteal muscle groups.

The IPP protocol also focused on a gradual increase in warm-up intensity with the same 3-phase setup as the DWU. The DWU and IPP included similar exercises, but the IPP also incorporated balance and plyometric exercises. All 3 warm-up programs were limited to 10 to 12 minutes to mimic the time allotted to a normal warm-up. We stressed proper technique throughout the IPP, using general cues, such as "land softly," "bend your knees and hips," "keep your toes facing forward," and "keep your knees over your toes." The IPP was developed from previous anterior cruciate ligament (ACL) IPPs that have been shown to reduce injury rates and modify neuromuscular risk factors in youth athletes.[15] Despite the variations in exercises and cuing, all 3 warm-up protocols were completed in 10 to 12 minutes.

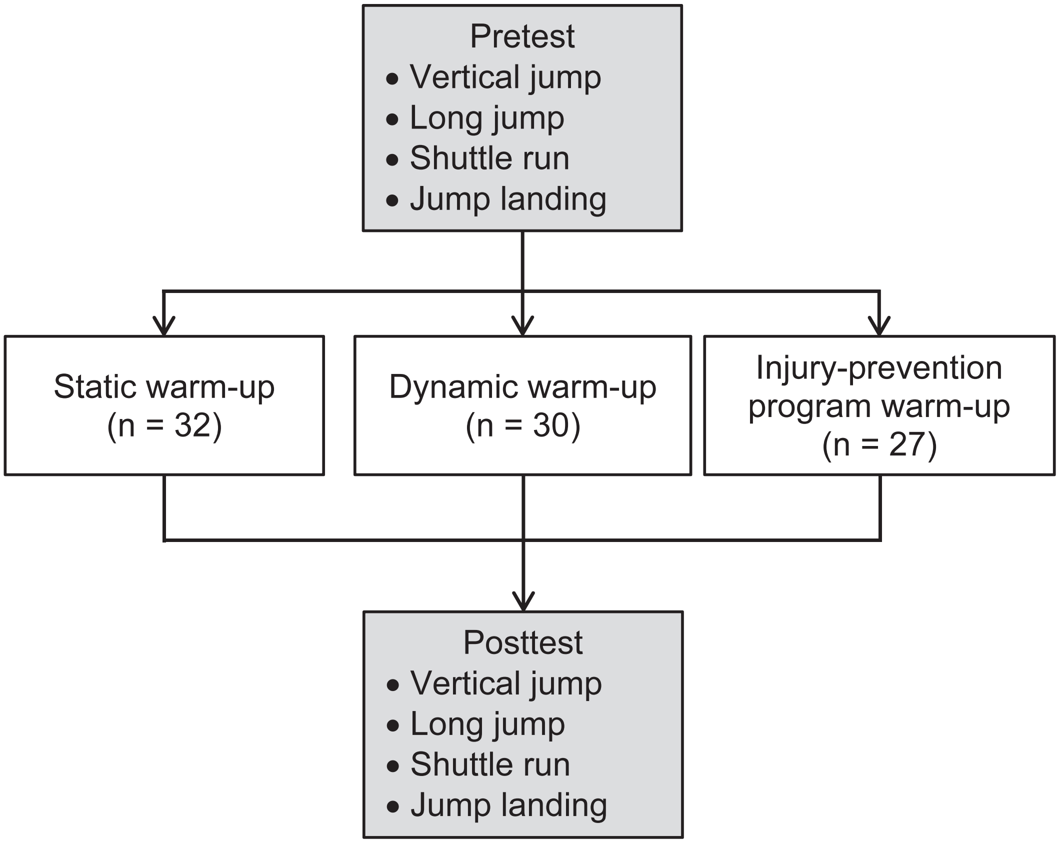

Figure 1. Flowchart of study procedures.

Movement Assessment

Participants performed 3 trials of a jump-landing task.[30] They jumped forward a distance of 50% of their body height from a 30-cm–high box and immediately jumped for maximal height after landing in the target area, which was indicated by a taped line on the floor. Participants did not receive feedback or coaching on jumping technique. They were given as many practice trials as needed to perform the task successfully. A *successful jump* required participants to (1) jump off with both feet from the box, (2) jump forward but not vertically to reach the target area, (3) land with both feet in the target area, and (4) immediately jump to maximal height, all in a fluid motion.

Table 2. Static Warm-Up Protocol[a]

Exercise	Description
5-min jog	Jog around the perimeter of the basketball courts at a pace slow enough for each athlete to carry on a conversation comfortably.
Hip-adductor stretch	Standing with feet shoulder-width apart, lunge sideways, and lean toward the same side to feel a stretch in the opposite inner thigh area.
Modified hurdler	In a seated position with 1 lower limb straight, place the other limb on the inside of the straight limb and reach forward.
Hip-flexor stretch	Kneel on 1 lower limb with the other limb in front of the body and the foot on the ground. Lean forward toward the front limb to feel a stretch in the back of the hip.
Quadriceps stretch	In the standing position with an erect spine, bend 1 knee and bring the heel toward the buttocks while holding the foot with 1 hand.
Gastrocnemius and soleus complex	In a push-up position, bring the feet forward until the heels are on the ground. Keep 1 foot on the ground and cross the other foot on top of the stretched lower limb.

[a] Each stretch was held for approximately 30 seconds before switching to the opposite side for an additional 30-second stretch.

Two standard digital video cameras (model FS400; Canon USA Inc, Lake Success, NY) were stationed at the front and side of the participants to capture frontal- and sagittal-plane views of each person completing the jump-landing task. A single rater (H.R.) who was blinded to time and group later analyzed the video footage using the LESS. The LESS is a valid and reliable clinical movement-assessment tool for identifying high-risk movement patterns during jump-landing tasks (Table 5).[30] The LESS scores are based on observable jump-landing errors, with a high score indicating poor technique and a corresponding higher risk of lower extremity injury. Movement errors are operationally defined, and 18 of the variables are scored on a binomial scale of 1 point for *error* and 0 points for *no error*, with the default scored as *no error*. Two additional variables give a global assessment of the jump-landing quality and are scaled from 0 to 2 points.[31] Another item was a variable that evaluated if participants landed with a visual weight shift, because Xergia et al[32] proposed landing asymmetry as an additional risk factor for ACL injury. Finally, the LESS score also included an excessive trunk-flexion–displacement variable, given that Frank et al[33] identified poor trunk control as a potential ACL injury risk

Table 3. Dynamic Warm-Up Protocol[a]

Exercise	Description	Key Points
High-knee walk	While walking, lift knee toward chest, raise the body on the toes, and swing alternating upper limbs.	Toes point straight ahead. Keep knee slightly bent.
Straight-leg march	While walking with both upper limbs extended in front of the body, lift 1 extended lower limb toward the hands and then return to the starting position before repeating with the other lower limb.	Raise lower limb to a lower height if needed to keep the knee straight when lifting. Toes point straight ahead.
Hand walk	With the hands and feet on the ground and the limbs extended, walk the feet toward the hands while keeping the limbs extended and then walk the hands forward while keeping the limbs extended.	Toes point straight ahead.
Lunge walk	Lunge forward with alternating lower limbs while keeping the torso vertical.	Toes point straight ahead. Hips face forward. Knees are over toes.
High-knee skip	While skipping, emphasize height, high-knee lift, and upper limb action.	Toes point straight ahead. Knees are over toes. Land as softly as possible.
Lateral shuffle	Start with the feet shoulder-width apart and the knees in a squatting position. Shuffle sideways and repeat in the opposite direction.	Toes point straight ahead. Knees are over toes. Sit back. Weight is on toes. Land as softly as possible.
Back pedal	While keeping the feet under the hips, take small steps to move backward rapidly.	
Heel-up "butt-kick"	With the hands on the hips, step forward with 1 lower limb while keeping the heel of the other foot on the ground. Feel the stretch in the back of the lower leg.	Toes point straight ahead. Chest faces forward.
High-knee run	Jog forward while bringing alternate knees to the chest.	Toes point straight ahead. Keep knee slightly bent. Swing upper limbs.

[a] Cones were placed at the starting line, at 10 m, and at 20 m. Athletes completed the designated exercise for the first 10 m, accelerated in a run for the second 10 m, and completed a recovery jog from the end line back to the starting line.

factor. The total LESS score is a valid measure of injury risk because it can differentiate youth athletes who sustain ACL injuries from those who do not in subsequent sessions.[31]

Performance Measures

All research assistants who measured and recorded performance data were blinded to group assignment.

Vertical Jump. Maximum vertical-jump height was measured using the Vertec device (Sports Imports, Columbus, OH). Participants started the vertical-jump task by standing under the Vertec with their upper extremities and hands fully extended vertically to obtain initial reach height. Next, they executed a double-limb countermovement jump to touch the highest bar possible. Participants performed 1 practice jump and 2 trial jumps.

Standing Long Jump. We measured standing–long-jump performance using a standard flat tape measure secured to the ground from a designated starting line. Participants began in a standing position at a marked starting line and were instructed to jump for maximum distance. They were allowed to move their upper and lower extremities as preferred to begin the task as long as their feet remained stationary. For each trial, the recorded distance was measured from the back of the heel closest to the starting line to that line. If a participant fell or could not keep his or her balance during the landing, the trial was excluded, and the participant jumped again.

Shuttle Run. Shuttle-run time was measured to the nearest 0.01 second using dual-beam electronic timing gates (TC-Speed-Trap II Wireless Timing System; Gill Athletics, Champaign, IL). Participants began at a designated starting line, which was marked with cones and a line taped to the floor. We marked an end line 30 m away with the cones and a line taped to the floor. One successful trial required participants to complete 2 repetitions of a 30-m down-and-back sprint (ie, 2 repetitions totaled 120 m) to the marked lines. Each participant completed a practice run and 2 trial runs, resting approximately 1 minute between runs.

Data Analysis

We checked all data for normality and homogeneity of variance. All trials for each dependent variable (vertical-jump height, long-jump distance, shuttle-run time, LESS score) were averaged for 1 composite score at PRE and POST. Change scores were calculated for each dependent variable by subtracting PRE values from POST values. Separate 1-way between-groups (IPP, SWU, DWU) analysis-of-variance tests were performed for each dependent variable. If the 1-way analysis of variance was different, we evaluated the 95% confidence interval (CI) of each pairwise group difference as a post hoc analysis. The α level was set a priori at .05. All data were analyzed using SPSS statistical software (version 21.0; IBM Corporation, Armonk, NY).

RESULTS

All participants completed the PRE and POST test sessions and an intervention program. All 3 groups were similar at baseline for all demographic information (age, height, mass, and current sport; $P > .05$). We noted a difference between groups for the LESS change score ($F_{2,83} = 3.48$, $P = .04$; Table 6), as the IPP resulted in a greater improvement in LESS score than the SWU (group difference [mean $\pm$ standard error] = –0.83 $\pm$ 0.33; 95% CI = –1.47, –0.18) and the DWU (–0.67 $\pm$ 0.337; 95% CI = –1.34, –0.002; Figure 2). We did not observe differences

Table 4. Injury-Prevention Warm-Up Program[a]

Exercise	Description	Key Points
Walking quad: 10 repetitions with each limb	Hold the heel of 1 lower limb close to the buttock to feel a stretch in the front of the thigh. Balance on the other limb with the knee slightly bent. Hold for 3 s.	Keep balance limb slightly bent. Toes point straight ahead.
Walking butt-kick: 10 repetitions with each limb	Actively lift the heel as close to the buttock as possible while balancing on the other limb with the knee slightly bent. Alternate.	Toes point straight ahead. Motion is controlled.
Hand walk: 10 repetitions with each lower limb	With the hands and feet extended on the ground, walk the feet toward the hands while keeping the lower limbs extended. Walk the hand forward while keeping the limbs extended. Alternate.	Toes point straight ahead.
Straight-leg march: 10 repetitions with each lower limb	Step forward and balance on 1 lower limb. Raise the other limb straight ahead while keeping the knee straight.	Raise lower limb to lower height if needed to keep the knee straight. Toes point straight ahead.
180° jump to balance: 30 s on each lower limb	Place the hands on the hips, jump vertically, and rotate 180°. Land softly with the trunk, hips, and knees flexed. Hold this position for 3 s.	Land softly. Bend the knees, hips, and trunk. Knees are over toes. Toes point straight ahead.
Double squat: 2 sets of 5	Stand with the feet shoulder-width apart and squat down slowly as if sitting in a chair. Return to the starting position.	Toes point straight ahead. Knees are over toes. Sit back.
Squat jump: 5, rest, 5	Squat down, jump for maximum height, and land softly in a squatting position.	Land low. Land softly. Knees are over toes.
Toe walk: 10 repetitions with each lower limb	Raise the heels from the ground and step forward, alternating lower limbs.	Toes point straight ahead. Keep the chest facing forward.
Forward lunge: 10 repetitions with each lower limb	Keep the hands on the hips, step forward with 1 foot, and lower the body to the ground. Bring the opposite knee as close to the ground as possible. Alternate.	Toes point straight ahead. Hips face forward. Knees are over toes.
Double-legged heel raise: 20 repetitions	Place the hands on the hips. Raise the heels off the ground and slowly lower them back down. Repeat.	Toes straight ahead. Knees are over toes.
Hip bridge: lift 1 s, hold 3 s, lower 2 s; 10 repetitions	Lay with the back on the ground, knees bent, and feet flat on the ground. Slowly lift hips off the ground and hold. Place hands on the hips and elbows on the ground. Progress to placing the upper limbs across chest.	Draw navel toward the spine while breathing. Keep the body in a straight line. Toes point straight ahead. Knees are over toes.
Double-legged forward line hop: 20 repetitions	Place the hands on the hips. Bounce forward and backward over the line. Start hopping for quality and then progress speed.	Toes point straight ahead. Knees are over toes. Stay on balls of feet. Land as softly as possible.
Side shuffle each way	Start with the feet shoulder-width apart and the knees in a squatting position. Shuffle sideways and repeat in the opposite direction.	Toes point straight ahead. Knees are over toes. Sit back. Weight on toes.
Forward skipping	Skip forward using the upper limbs for momentum. Start skipping for proper technique and then progress speed.	Toes point straight ahead. Knees are over toes. Land as softly as possible.

[a] The cone setup was identical to that used for the dynamic warm-up protocol (Table 3).

between groups in change scores for the vertical jump, long jump, or shuttle run ($P > .05$). We also did not find baseline differences between groups for any of the dependent variables (vertical-jump height, long-jump distance, shuttle-run time, or LESS score; $P > .05$; Table 7).

DISCUSSION

Our results provided evidence that an IPP can immediately improve jump-landing technique without impairing performance in youth athletes. The IPP caused participants to improve landing technique by 0.5 points on average, with the opposite response occurring after the SWU and no change after the DWU. Given that lower extremity injuries, particularly of the ACL, are frequently a combination of multiple injurious movement patterns and sport-specific circumstances, the presence or absence of an additional biomechanical risk factor (equivalent to 1 full point on the LESS) may be the difference between a season-ending injury and health. We hope that these positive results after a single IPP session will further encourage long-term program adoption, improve compliance rates, and perpetuate success with greater reductions in injury rates.

Researchers[10,13,34,35] have shown that exercise-based IPPs can successfully modify several lower extremity risk factors, such as knee-flexion angle and vertical ground reaction force, as well as lower the absolute injury rate after a season-long intervention. However, positive results hinge on compliance, and players with the greatest compliance will tend to see the greatest reductions in injury rates.[22] Our results indicated an immediate benefit to implementing programs, which could provide instant gratification to players and coaches. Because the LESS is a binary score (error present versus error absent) for biomechanical movement, it is reasonable to assume that making multiple gross changes in movement pattern after just one 10-minute session would be too difficult. However, the ability to make 1 acute change after a single session is promising and further emphasizes the need for continued use of an IPP to potentially see changes across multiple biomechanical risk factors.

Table 5. Landing Error Scoring System

1. Knee flexion at initial contact: <30°	☐ No error (0)	☐ Error (1)			
2. Hip flexion at initial contact: hips are NOT flexed	☐ No error (0)	☐ Error (1)	☐ Left	☐ Right	☐ Both
3. Trunk flexion at initial contact: trunk is NOT flexed	☐ No error (0)	☐ Error (1)			
4. Ankle plantar flexion at initial contact: land heel to toe or flat foot	☐ No error (0)	☐ Error (1)	☐ Left	☐ Right	☐ Both
5. Asymmetrical timing: feet do NOT land at the same time	☐ No error (0)	☐ Error (1)	☐ Left	☐ Right	
6. Asymmetrical heel-toe/toe-heel: 1 foot lands flat/heel-toe, and the other foot lands toe-heel	☐ No error (0)	☐ Error (1)	☐ Left	☐ Right	
7. Lateral trunk flexion at initial contact: trunk is NOT vertical	☐ No error (0)	☐ Error (1)			
8. Medial knee position at initial contact: knee medial to midfoot	☐ No error (0)	☐ Error (1)	☐ Left	☐ Right	
9. Wide stance width: > shoulder width	☐ No error (0)	☐ Error (1)			
10. Narrow stance width: < shoulder width	☐ No error (0)	☐ Error (1)			
11. Maximum internal-rotation foot position: toes > 30° of internal rotation	☐ No error (0)	☐ Error (1)	☐ Left	☐ Right	☐ Both
12. Maximum external-rotation foot position: toes < 30° of internal rotation	☐ No error (0)	☐ Error (1)	☐ Left	☐ Right	☐ Both
13. Knee-flexion displacement: < additional 45° of flexion after initial contact	☐ No error (0)	☐ Error (1)			
14. Hip-flexion displacement: hips DO NOT flex more than at initial contact	☐ No error (0)	☐ Error (1)			
15. Trunk-flexion displacement: trunk DOES NOT flex more than at initial contact	☐ No error (0)	☐ Error (1)			
16. EXCESSIVE trunk-flexion displacement: trunk flexion past parallel with lower leg	☐ No error (0)	☐ Error (1)			
17. Maximum medial knee position: > great toe	☐ No error (0)	☐ Error (1)			
18. Asymmetrical loading: a weight shift is present (1 side is loaded more than the other)	☐ No error (0)	☐ Error (1)	☐ Left	☐ Right	
19. Joint displacement: sagittal plane	☐ Soft (0)	☐ Average (1)	☐ Stiff (2)		
20. Overall impression	☐ Excellent (0)	☐ Average (1)	☐ Poor (2)		

Table 6. Landing Error Scoring System Scores

Group	Score (Mean ± SD) Pretest	Posttest	Change	95% Confidence Interval
Injury-prevention program	7.03 ± 2.10	6.63 ± 1.99	−0.40 ± 1.24[a]	−0.88, 0.09
Static warm-up	6.95 ± 1.85	7.38 ± 1.84	0.43 ± 1.35	−0.01, 0.86
Dynamic warm-up	6.50 ± 2.04	6.77 ± 2.04	0.27 ± 1.09	−0.19, 0.74

[a] Indicates difference between groups ($F_{2,83} = 3.48$, $P = .04$).

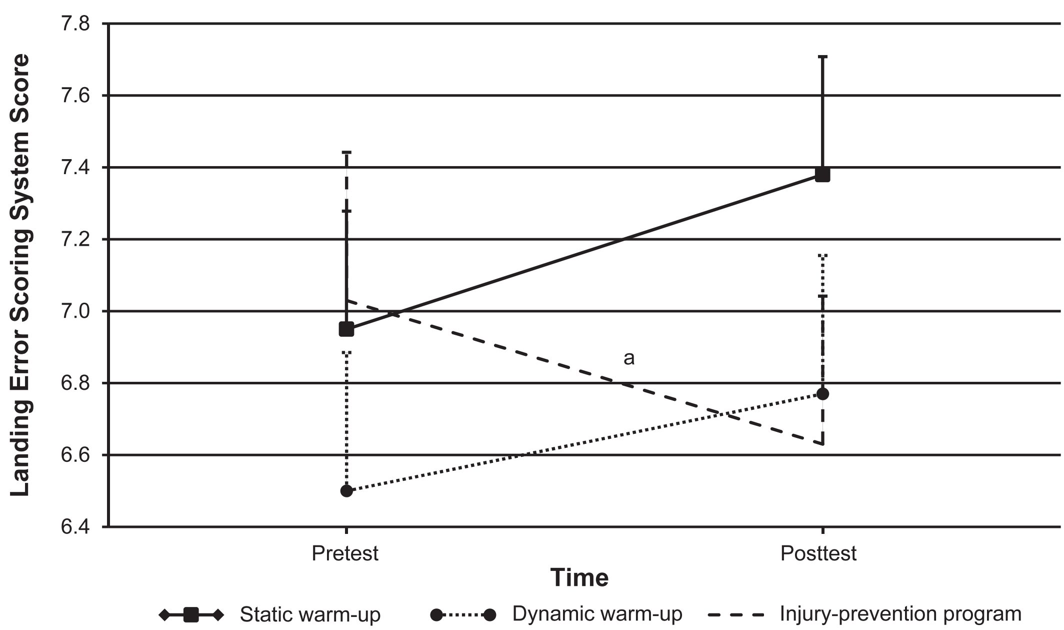

Figure 2. Mean Landing Error Scoring System score by group across time. [a] Indicates difference ($P = .04$).

Table 7. Performance Variable Measurements (Mean ± SD)

Performance Variable	Group	Measurement			
		Pretest	Posttest	Change Score	95% Confidence Interval
Vertical jump, in (cm)	Injury-prevention program	17.06 ± 4.97 (43.33 ± 12.62)	17.45 ± 4.11 (44.32 ± 10.44)	0.65 ± 2.19 (1.65 ± 5.56)	−0.23, 1.54 (−0.58, 3.91)
	Static warm-up	16.60 ± 3.43 (42.16 ± 8.71)	16.59 ± 3.45 (42.14 ± 8.76)	−0.02 ± 1.36 (−0.05 ± 3.45)	−0.50, 0.47 (−1.27, 1.19)
	Dynamic warm-up	16.83 ± 3.31 (42.75 ± 8.41)	16.88 ± 3.06 (42.88 ± 7.77)	0.04 ± 2.01 (0.10 ± 5.11)	−0.71, 0.79 (−1.80, 2.01)
Long jump, in (cm)	Injury-prevention program	66.95 ± 14.12 (170.05 ± 35.86)	66.80 ± 13.73 (169.67 ± 34.87)	−0.16 ± 4.01 (−0.41 ± 10.19)	−1.74, 1.43 (−4.42, 3.63)
	Static warm-up	65.51 ± 11.33 (166.40 ± 28.78)	63.55 ± 11.72 (161.42 ± 29.77)	−1.95 ± 3.90 (−4.95 ± 9.91)	−3.36, −0.55 (−8.53, −1.40)
	Dynamic warm-up	65.09 ± 11.72 (165.33 ± 29.77)	64.04 ± 11.19 (162.66 ± 28.42)	−1.05 ± 5.60 (−2.67 ± 14.22)	−3.14, 1.04 (−7.98, 2.64)
Shuttle run, s	Injury-prevention program	10.59 ± 1.06	10.72 ± 1.26	0.12 ± 0.50	−0.09, 0.32
	Static warm-up	10.36 ± 1.00	10.36 ± 1.40	0.01 ± 0.93	−0.33, 0.34
	Dynamic warm-up	10.58 ± 1.03	10.55 ± 1.05	−0.02 ± 0.52	−0.22, 0.17

In many recent studies, researchers[36–39] have used IPPs to target high school athletes, and Grandstrand et al[40] reported that some coaches may be concerned that an IPP involves exercises that are too difficult for young children to complete. However, the average participant's age in our study was 13 ± 2 years, and the IPP group members successfully completed the entire warm-up during their first exposure; no one dropped out of the program due to discomfort or injury. Given that youth athletes have not reached their neuromuscular growth spurts and are continuously developing motor-learning skills[41] and that high school-aged athletes are at dramatically increased risk for sustaining ACL injuries,[3] a middle school population should be targeted to receive instruction in correct movement patterns.

Investigators[42–46] have shown that providing adults and youths with oral cues on which to focus can acutely modify lower extremity movement patterns during a jump-landing task. In agreement with these findings, the youth athletes in our study who completed the IPP achieved relatively more improvement in jump-landing technique than the athletes who completed the other 2 warm-up programs. Whereas the change within the IPP group was not different (change score 95% CI = –0.88, 0.09), we believe this acute effect may still be clinically meaningful. This result suggests that the athletes translated the instructions and feedback provided during the single session of the IPP and made preliminary improvements during the standardized jump-landing task compared with the other programs. We recognize that the magnitude of change is relatively small, but acute benefits after a single session may have an additive benefit of athletes exhibiting increased improvements after each session. Although we did not study these patterns postpractice or over the course of a season, Padua et al[47] showed that long-term retention of biomechanical movement patterns is linked to the duration of the program, with the optimal program length exceeding 3 months. Therefore, it is necessary to identify other benefits that could encourage proper, continued, repetitive use of IPPs to increase the likelihood of sustaining long-term effects.

Using surveys on coaching and player attitudes, Saunders et al[48] also observed that coaches and players alike would prefer to couple injury-prevention efforts with athlete performance enhancement. Coaches are concerned that their athletes may become overly fatigued if they perform an IPP before athletic events.[48] We are the first, to our knowledge, to address this concern and evaluate the acute effects of an IPP on performance gains in youth athletes compared with other warm-up methods. DiStefano et al[25] showed improved balance ability and vertical-jump performance in youth athletes after a 9-week IPP. We studied a similar age group but did not observe any acute performance improvements. Consistent implementation of an IPP over the course of a season may be necessary to see performance gains in a neuromuscularly immature population.[25] Most importantly, our observations indicated that the IPP is not acutely detrimental to performance. The IPP was just as effective as the DWU in preparing the athletes for performance tasks. This indicates that the IPP athletes were adequately prepared to complete performance tasks and were not too fatigued from the program, which are 2 common concerns of coaches when considering implementation of an IPP.

We also observed that the SWU and DWU protocols neither improved nor decreased performance measures. Our DWU results are in contrast with the current literature, in which researchers[28,29] have detected acute improvements with DWUs. Aguilar et al[28] recently demonstrated that a DWU program can elicit acute strength and flexibility improvements compared with an SWU, and Faigenbaum et al[29] showed that a youth population might also experience acute performance gains after a DWU. Although our study population was similar to that of Faigenbaum et al,[29] our between-groups design, and thus between-groups variability, may have reduced our capacity to detect changes in the performance measures.

Overall, our IPP demonstrated acute improvements in jump-landing technique and did not negatively affect performance variables. Athletes between the ages of 11 and 15 were able to take generalized cues, such as "land softly" and "knees over toes," and immediately translate them into sport-specific movement tasks, theoretically reducing the risk of lower extremity injury. Furthermore, we did not observe negative performance effects, indicating that IPPs are as effective as both SWUs and DWUs in preparing an athlete for competition. These results can help to encourage teams to implement IPPs and alleviate concerns of coaches and athletes that an IPP will impair performance before sport participation.

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