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Thigh Muscle Activity, Knee Motion, and Impact Force During Side-Step Pivoting in Agility-Trained Female Basketball Players

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Context: Improving neuromuscular control of hamstrings muscles might have implications for decreasing anterior cruciate ligament injuries in females.

Objective: To examine the effects of a 6-week agility training program on quadriceps and hamstrings muscle activation, knee flexion angles, and peak vertical ground reaction force.

Design: Prospective, randomized clinical research trial.

Setting: Sports medicine research laboratory.

Patients or Other Participants: Thirty female intramural basketball players with no history of knee injury (age = 21.07 ± 2.82 years, height = 171.27 ± 4.66 cm, mass = 66.36 ± 7.41 kg).

Intervention(s): Participants were assigned to an agility training group or a control group that did not participate in agility training. Participants in the agility training group trained 4 times per week for 6 weeks.

Main Outcome Measure(s): We used surface electromyography to assess muscle activation for the rectus femoris, vastus medialis oblique, medial hamstrings, and lateral hamstrings for 50 milliseconds before initial ground contact and while the foot was in contact with the ground during a side-step pivot maneuver. Knee flexion angles (at initial ground contact, maximum knee flexion, knee flexion displacement) and peak vertical ground reaction force also were assessed during this maneuver.

Results: Participants in the training group increased medial hamstrings activation during ground contact after the 6-week agility training program. Both groups decreased their vastus medialis oblique muscle activation during ground contact. Knee flexion angles and peak vertical ground reaction force did not change for either group.

Conclusions: Agility training improved medial hamstrings activity in female intramural basketball players during a side-step pivot maneuver. Agility training that improves hamstrings activity might have implications for reducing anterior cruciate ligament sprain injury associated with side-step pivots.

Key Words: anterior cruciate ligament, injury prevention, knee sprains

Key Points

- The agility training program increased medial hamstrings activation during the loading phase of the side-step pivot maneuver, but it did not affect lateral hamstrings, vastus medialis oblique, or rectus femoris activation.
- Knee flexion kinematics and normalized peak vertical ground reaction force did not change from pretest to posttest, suggesting that the increased medial hamstrings activation in the training group was not influenced by kinematics or peak vertical ground reaction forces.
- Increasing hamstrings activation through an agility training program might limit excessive anterior tibial translation during functional movement, helping to prevent anterior cruciate ligament sprain.

Sports medicine clinicians have faced the challenging problem of how to prevent anterior cruciate ligament (ACL) injuries in physically active females because females are more likely than males to injure their ACLs.[1,2] An increased incidence of ACL injury in females might result from anatomical, environmental, hormonal, neuromuscular, or biomechanical factors.[3] Researchers[3–11] have speculated that noncontact ACL injuries in females result from deceleration cutting, side-step pivoting, and jump landings with the knee in an extended and excessively valgus position. They think that, in this vulnerable knee position, the ACL becomes strained excessively because it cannot stabilize the knee effectively, which could predispose the ACL to injury.[5,7,11,12]

Female athletes have been reported to have altered muscle-timing patterns, as well as increased quadriceps activation compared with hamstrings activation.[11,13–15] Increased quadriceps muscle activation relative to hamstrings muscle activation might allow excessive anterior tibial translation, increasing the amount of strain imposed on the ACL during functional activities.[5,11,13,16–18] Therefore, impaired neuromuscular control might be a contributing factor to the increased frequency of noncontact ACL injury in females. Consequently, training programs that emphasize neuromuscular control have been recommended for reducing the incidence of ACL injury in female athletes.[6,12,19,20]

Neuromuscular control training has been successful in decreasing the incidence of ACL injury,[6,20] perhaps because training programs that focus on improving neuromuscular control enhance knee joint stability during jumping, cutting, and pivoting activities.[6,12,19,20] Researchers have recently suggested that neuromuscular training should include dynamic activities to improve knee joint stability.[6,12,18–22] Agility training is one example of a neuromuscular control training program that has been recommended for improving hamstrings muscle activation and enhancing dynamic knee joint stability by allowing a more rapid muscle response to anterior tibial translation joint perturbations by a knee testing apparatus.[18] Agility training combined with plyometric training and plyometric training alone have also improved knee joint neuromuscular control during jump landings.[21,22] Although agility training has positively influenced neuromuscular control under testing apparatus and jump-landing conditions, the effects of agility training on neuromuscular control during alternative movements associated with noncontact ACL injury are not known.

Side-step pivots are maneuvers performed during physical activity that might impose excessive strain on the ACL in the absence of adequate neuromuscular control.[5,8,11,23] Malinzak et al[11] reported that women perform side-step pivoting with increased knee extension, increased knee valgus, increased quadriceps activation, and decreased hamstrings activation compared with men. The increased anterior shear force and tibial translation that might result from increased quadriceps activation and decreased hamstrings activation is of great concern because strain on the ACL might increase.[5,11,13,16–18] Dynamic knee joint stability during a side-step pivot might be improved through adequate hamstrings activation before and during ground contact. Theoretically, agility training that improves hamstrings activation during side-step pivoting might have implications for decreasing noncontact ACL injuries in female athletes. Therefore, the primary purpose of this study was to examine the effects of a 6-week agility training program on quadriceps and hamstrings muscle activation during a side-step pivot maneuver. We hypothesized that agility training would increase hamstrings activation during the side-step pivot, whereas quadriceps activation would remain unaffected. A secondary purpose of this study was to examine the effects of agility training on knee joint kinematics and peak vertical ground reaction force (VGRF) because changes in kinematics and kinetics might influence muscle activation.[11,16]

METHODS

Study Design

For our prospective, randomized clinical research trial, we used a 2 × 2 × 2 mixed-model, repeated-measures design to compare group (training, control) across test (pretest, posttest) and across phase (preparatory, loading) for muscle activation dependent measures. Dependent measures for muscle activation included normalized mean amplitude muscle activity (percentage of maximal voluntary isometric contraction [%MVIC]) for the vastus medialis oblique (VMO), rectus femoris (RF), medial hamstrings (MH), and lateral hamstrings (LH). Additionally, we used a 2 × 2 mixed-model, repeated-measures design to compare group (training, control) across test (pretest, posttest) for knee kinematics and impact force dependent measures. Dependent measures for knee kinematics (degrees) included knee flexion at initial ground contact, maximum knee flexion, and knee flexion displacement. The dependent measure for impact force (multiple of body weight) was the peak VGRF normalized to body weight.

Participants

Thirty healthy women who engaged in intramural basketball participated in this study. Participants were randomly assigned to either a training group (n = 15; age = 21.07 ± 3.62 years, height = 171.49 ± 5.65 cm, mass = 67.58 ± 7.71 kg) or a control group (n = 15; age = 21.07 ± 1.83 years, height = 171.06 ± 3.60 cm, mass = 65.13 ± 7.14 kg). Characteristics of participants did not change between test sessions. They had to meet the following criteria to participate in this study: (1) no history of knee surgery or injury, (2) no participation in a formal injury-prevention training program within the 6 months before the study, and (3) participation in intramural basketball for a minimum of 2 times per week. All participants gave informed consent, and the Committee for the Protection of the Rights of Human Subjects granted approval for this project.

Instrumentation

An 8-channel Konigsberg telemetry electromyography (EMG) system (model T42L-8TO; Konigsberg Instruments, Inc, Pasadena, CA) was used to determine muscle activation amplitude of the VMO, RF, MH, and LH. We used bipolar Ag/AgCl surface electrodes (Medicotest, Inc, Rolling Meadows, IL) that were 10 mm in diameter and had a center-to-center distance of 2.0 cm. Surface EMG was recorded for MVIC and the side-step pivot maneuver. Electromyographic signals were sampled at 1440 Hz and were amplified by a factor of 10 000 over a bandwidth of 0.01 to 2000.00 Hz. The EMG system used a 2-channel differential preamplifier/encoder/transmitter and a receiver/demodulator (input impedance = 200 kΩ, common-mode rejection ratio > 70 dB, signal-to-noise ratio > 40 dB). A telemeter transmitted EMG signals to a base station. An analog-to-digital converter (National Instruments Corp, Austin, TX) passed EMG signals to a storage computer.

A Flock of Birds electromagnetic motion analysis system (Ascension Technologies, Inc, Burlington, VT) controlled by MotionMonitor software (Innovative Sports Training, Inc, Chicago, IL) sampled knee kinematics at 144 Hz during the side-step pivot maneuver. Electromagnetic tracking sensors were placed on the apex of the sacrum, midpoint of the thigh, midpoint of the lower leg, and top of the foot. Sensor data were used for calculating sensor position and orientation. Knee and subtalar joints were calculated by manually digitizing 2 points on opposite sides (medial-lateral) of each joint. Joint center of rotation was calculated at the centroid between these 2 points for both the knee and ankle. The foot was calculated by digitizing the subtalar joint and the tip of the second phalanx. The hip was calculated by using the Leardini method that was available in the MotionMonitor software.

A transmitter was positioned on a custom tripod to enable the establishment of a global reference system. The global reference system axes were designed so that the y-axis was designated as positive anteriorly, the x-axis was designated as positive toward the lateral aspect (right) of the participant, and the z-axis was designated as positive superiorly. These axes were aligned with the cardinal axes.

A nonconductive force plate (model 4060-NC; Bertec Corp, Columbus, OH) sampled peak VGRF at 1440 Hz. Peak VGRF was used to synchronize EMG and kinematic data. The orthogonal coordinates of the force plate were aligned with the global reference system of the transmitter. Signals from the force plate were passed through an analog-to-digital converter in the Flock of Birds system.

Testing Procedures

Participants performed a side-step pivot maneuver on 2 separate occasions (pretraining, posttraining) in our Sports Medicine Research Laboratory. Pretesting occurred before the start of the agility training program. The agility group participants performed their posttests after successful completion of the 6-week agility training program. Participants in the control group were tested 6 weeks after their initial testing sessions. All testing was conducted on the dominant leg, which was defined as the leg used to kick a ball. To eliminate the effects of fatigue, we did not test participants within 1 hour of a practice or game. Participants wore basketball shoes, spandex or loose-fitting shorts, and T-shirts for test sessions.

Maximal Voluntary Isometric Contraction. Before application of surface electrodes, the skin was shaved, abraded, and cleaned with isopropyl alcohol. Surface electrodes were placed in a parallel arrangement over the muscle bellies during isometric contractions of the VMO, RF, MH, and LH. All electrode placements were confirmed with manual muscle testing to check for crosstalk. Surface electrodes were further secured using prewrap to prevent movement artifact and tension on the cables during the side-step pivot maneuver.

Participants were placed in a seated position on an isokinetic dynamometer (Biodex Medical Systems, Shirley, NY), and MVICs were performed for VMO, RF, LH, and MH. To obtain the MVIC, each participant had her thigh strapped to the isokinetic dynamometer with her knee flexed to 45°, performed isometric knee flexion contractions to measure hamstrings muscle activation, and performed isometric knee extension contractions to measure quadriceps muscle activation. The order of testing knee extension and knee flexion during MVIC assessment was randomized. To establish MVIC levels for the 4 muscles tested, we collected 3 maximal 5-second muscle contractions. Participants rested 30 seconds between trials.

Side-Step Pivot Maneuver. After MVIC testing, electromagnetic tracking sensors were secured with straps on the apex of the sacrum, midpoint of the thigh, midpoint of the lower leg, and top of the foot. Next, each participant ran in a straight line toward a force plate that was positioned 4 m away from the starting position. When reaching the force plate, the participant performed a side-step pivot maneuver by placing her dominant foot in direct contact with the force plate and pivoting 45° in the opposite direction of her plant leg. For example, a right-leg–dominant participant planted and pivoted to the left at 45°. To standardize the pivoting angle, a 1-ft (0.30-m)-wide alleyway was constructed with athletic tape and was placed on the ground extending from the force plate. The alleyway was placed at a 45° angle relative to the path of motion before contacting the force plate. Although pivoting angles vary among athletes, 45° has been used as a standard angle for side-step pivoting.[5,11,24] The participant was instructed to contact the force plate with her plant foot (dominant leg) pointing straight ahead and pivot 45° in the opposite direction. While performing the side-step pivot maneuver, the participant placed her trail foot (nondominant leg) in the alleyway, so that her foot contacted the ground pointing in the direction of the alleyway. Trials were acceptable when the plant foot landed straight ahead between the taped lines on the center of the force plate.

Side-pivoting trials in which the average approach speed of the participant was from 3.3 to 4.3 m/s were accepted for analysis. The speeds were calculated by 2 timers set 3 m apart. One was placed at the starting position, and the other was placed at the edge of the force plate where the side-step pivot maneuver was performed. Trials were repeated, and data were discarded for speeds less than 3.3 m/s or more than 4.3 m/s.

Participants performed 3 to 5 practice trials of the side-step pivot maneuver and then rested for 2 minutes before data collection. Next, participants performed 3 separate side-step pivot maneuvers. They rested for 20 seconds between side-step pivot trials.

Agility Training Protocol. Participants in the control group did not participate in any form of specialized agility training during the 6-week training period. The control group participants underwent initial testing and were retested after 6 weeks. During this 6-week period, control participants continued their regularly scheduled basketball practices and training schedules and were instructed not to change their regular training habits.

Our agility training program was developed from programs reported in the literature.[6,12,18,19,25–28] Participants in the agility training group performed agility drills 4 times per week for 6 weeks. Each training session lasted approximately 15 minutes. All agility training sessions were supervised by a certified athletic trainer (D.R.W.) to ensure that participants completed the agility training. The agility training program was designed as a 4-phase program (Figures 1 through 4). All participants were progressed through the 4 phases after 6 training sessions per phase. The agility training drills began with exercises stressing the basic principles of agility training, including foot speed and correct technique. The early phases of the agility training program incorporated drills for which participants had advance notice of the required motion patterns, direction changes, and speeds. As participants moved to the later phases of the agility training program, they progressed to performing unanticipated motion patterns and direction changes. Participants were permitted to miss a training session if they made up that session during the same or the following week. Participants could not have fewer than 3 or more than 5 training sessions per week. All participants adhered to these training requirements.

All exercises were demonstrated at the initial session of each phase through the use of an instructional video. Pins, rubber dots, athletic tape, and a ladder (7.7 m long, 0.4 m wide, 0.4 m between rungs) were used to set up agility training exercises. Participants performed 4 repetitions for

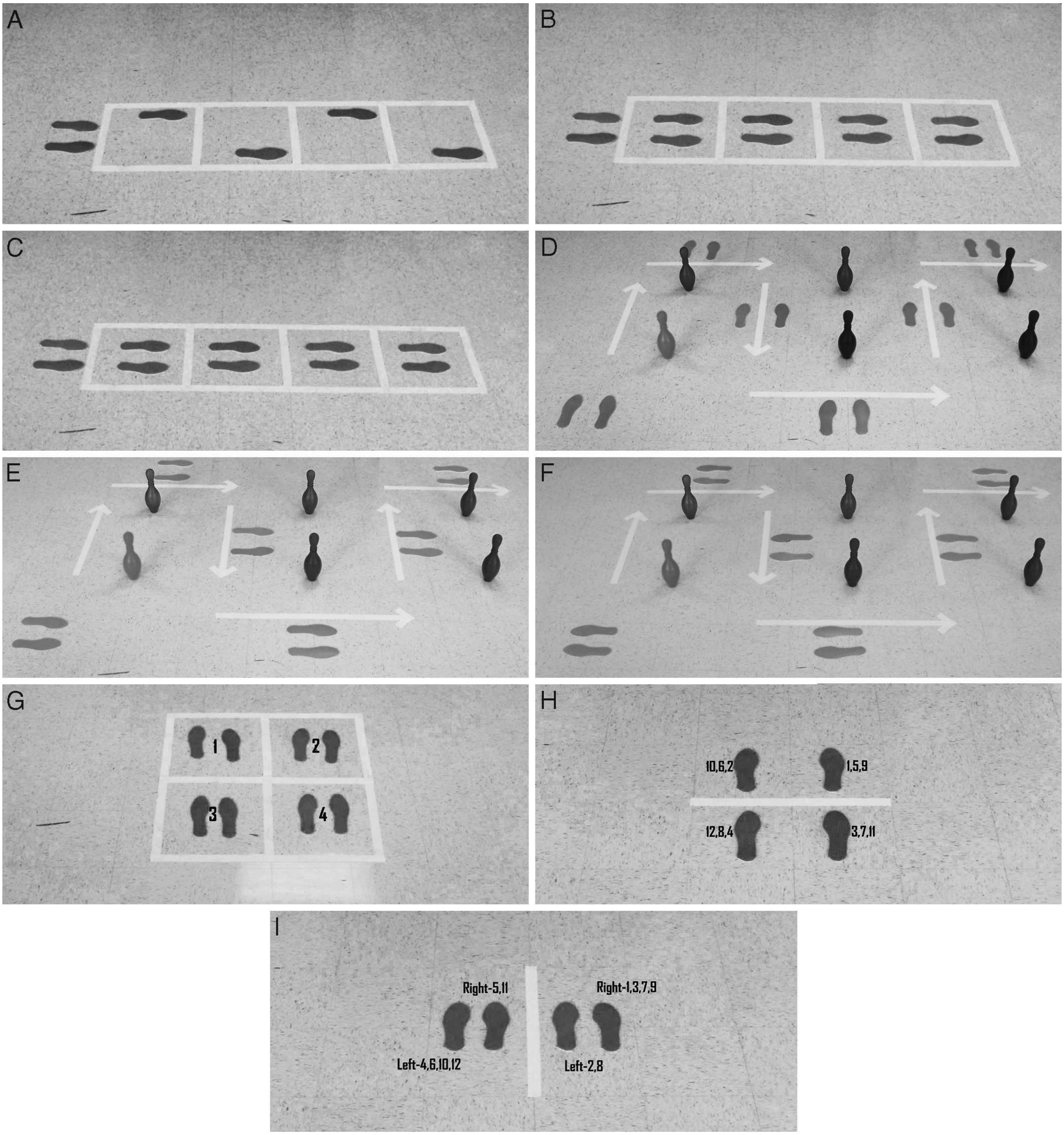

Figure 1. Phase 1 agility drills. A, Alternate-foot ladder sprint. B, Double-leg ladder hops. C, Quick-feet ladder sprint. D, Forward/backward sprints. E, Forward lateral shuffle. F, Backward lateral shuffle. G, Square drill with double-leg hop. The hop sequence is given. H, Line crossover. The steps are shown for the right foot. I, Side-to-side with stutter step. The sequence is given for the left and right feet.

each exercise before they moved to the next exercise in the training session. The work-to-rest ratio was 1:3 for all participants.[25] All ladder and zigzag drills required participants to sprint 4.5 m into the drill and sprint 4.5 m out of the drill. During the first session of each phase in the agility training program, emphasis was placed on proper body positioning (bent hips and knees with weight evenly distributed over the toes). Standardized feedback was provided to all participants to ensure consistent instruction.

Exercises performed during phase 1 agility drills included alternate-foot ladder sprint, double-leg ladder hops, quick-feet ladder sprint, forward/backward sprints, forward lateral shuffle, backward lateral shuffle, square drill with double-leg hop, line crossover, and side-to-side with stutter step (Figure 1). For forward/backward sprints, each participant placed both feet in each square and performed lateral shuffles to the right for the first sequence and to the left for the second sequence. The pattern for the square

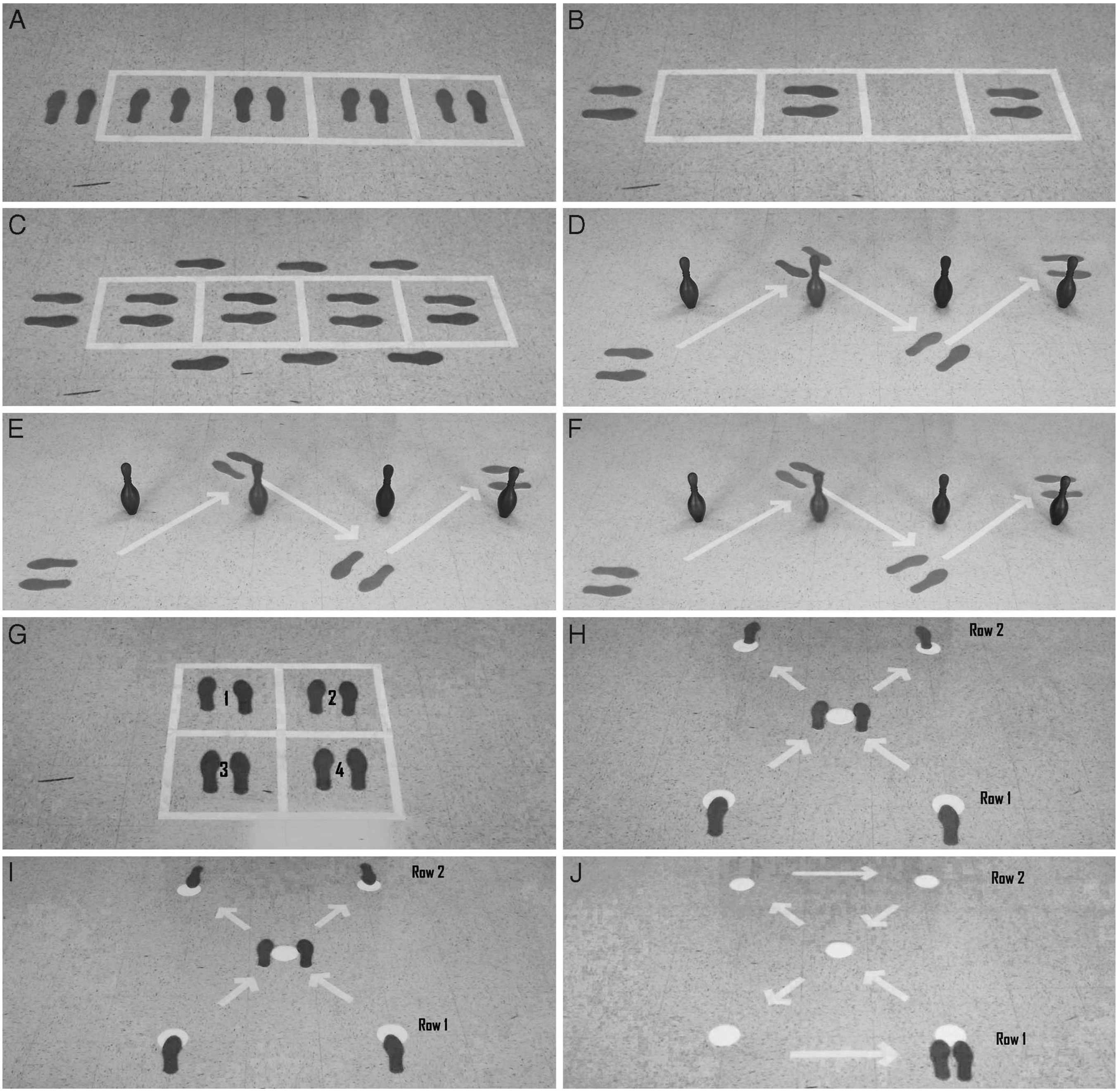

Figure 2. Phase 2 agility drills. A, Lateral shuffle. B, Double-leg hops. C, In-in/out-out. D, Forward zigzag. E, Backward zigzag. F, Forward/backward zigzag. G, Square drill with double-leg hop. H, 2-1-2 dot drill. I, Spin dot drill. J, Figure-of-8 dot drill.

drill with double-leg hop was 1-2, 1-3, 1-4, and 2-3. To perform the line crossover exercise, each participant led with the right foot for the first sequence and led with the left foot for the second sequence. After crossing over the line in the side-to-side with stutter-step drill, each participant lifted up her lead foot and placed it back down in the original position, then she crossed over the line step with the other foot.

Exercises performed during phase 2 agility drills included lateral shuffle, double-leg hops, in-in/out-out, forward zigzag, backward zigzag, forward/backward zigzag, square drill with double-leg hop, 2-1-2 dot drill, spin dot drill, and figure-of-8 dot drill (Figure 2). For the lateral shuffle, each participant placed both feet in each square and performed lateral shuffles to the right for the first sequence and lateral shuffles to the left for the second sequence. Each participant performed the in-in/out-out drill by placing her feet in the square consecutively and then placing them out of the square consecutively. The pins for both the forward and backward zigzag drills were set 4.5 m apart. For the forward/backward zigzag, the pins were set 4.5 m apart, and each participant pivoted 180° at each pin. She performed the first sequence starting at the right of the pin and the second sequence starting at the left of the pin. The square drill with double-leg hop was performed as in phase 1. The dots for each of the dot drills were set shoulder width apart. For the 2-1-2 dot drill, each participant moved forward to row 2 of the dots and then backward to row 1 of

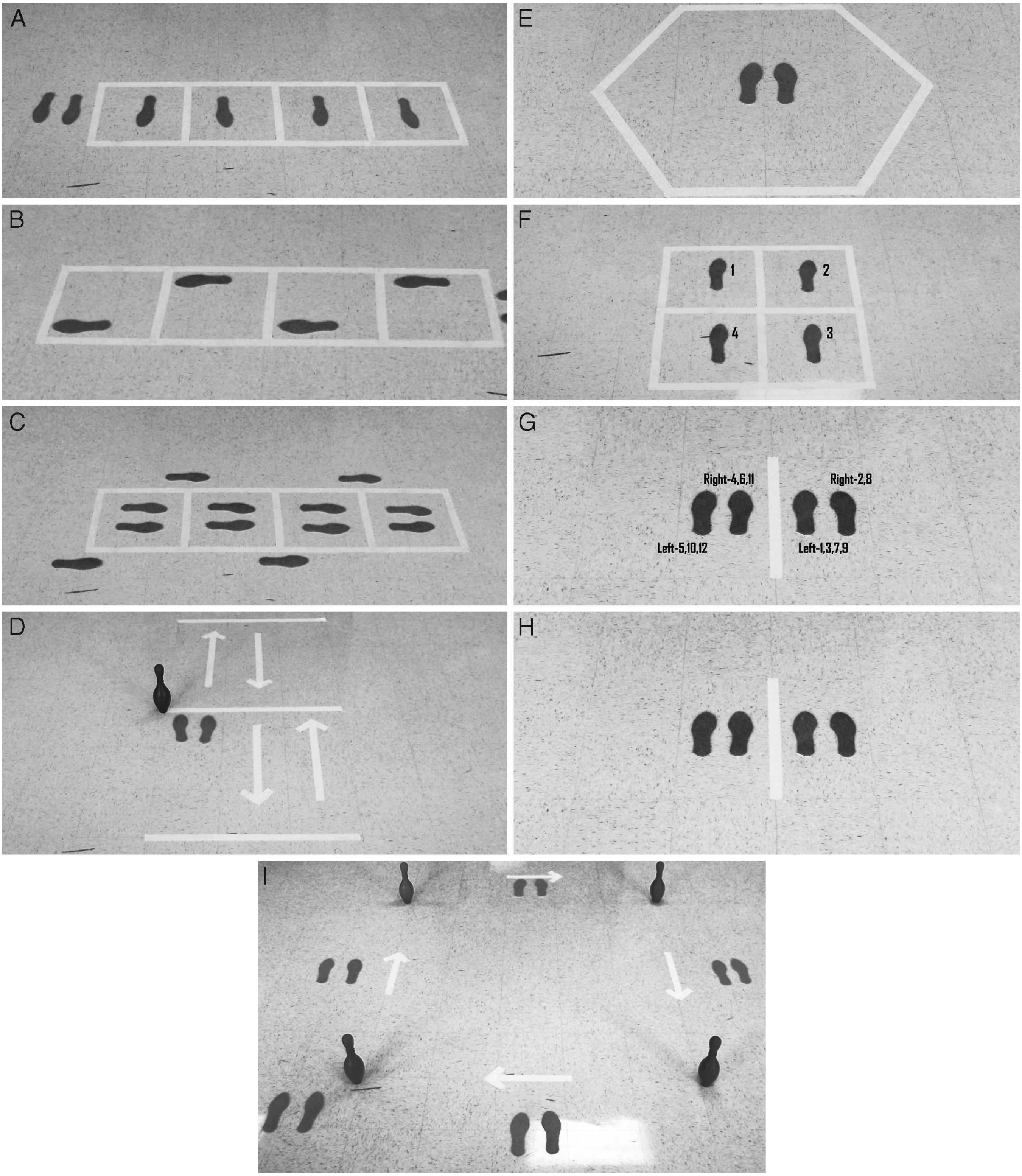

Figure 3. Phase 3 agility drills. A, Carioca. B, Backpedal. C, One foot out/2 feet in. D, Proagility drill. E, Hexagon test. F, Square drill with single-leg hop. The hop sequence is given. G, All crossover with stutter step. The step sequence is given for left and right feet. H, Side-to-side with 2-foot hop. I, Shuffle box.

the dots to complete 1 repetition; for the spin dot drill, she performed the 2-1-2 dot drill and spun 180° at the second row of dots; and for the figure-of-8 dot drill, she jumped on dots with both feet.

Exercises performed during phase 3 agility drills included a carioca, backpedal, 1 foot out/2 feet in, proagility drill, hexagon test, square drill with single-leg hop, all crossover with stutter step, side-to-side with 2-foot hop, and shuffle box (Figure 3). Each participant performed carioca to the right for the first sequence and to the left for the second sequence. The backpedal drill included every other square. For the 1 foot out/2 feet in drill, each participant placed

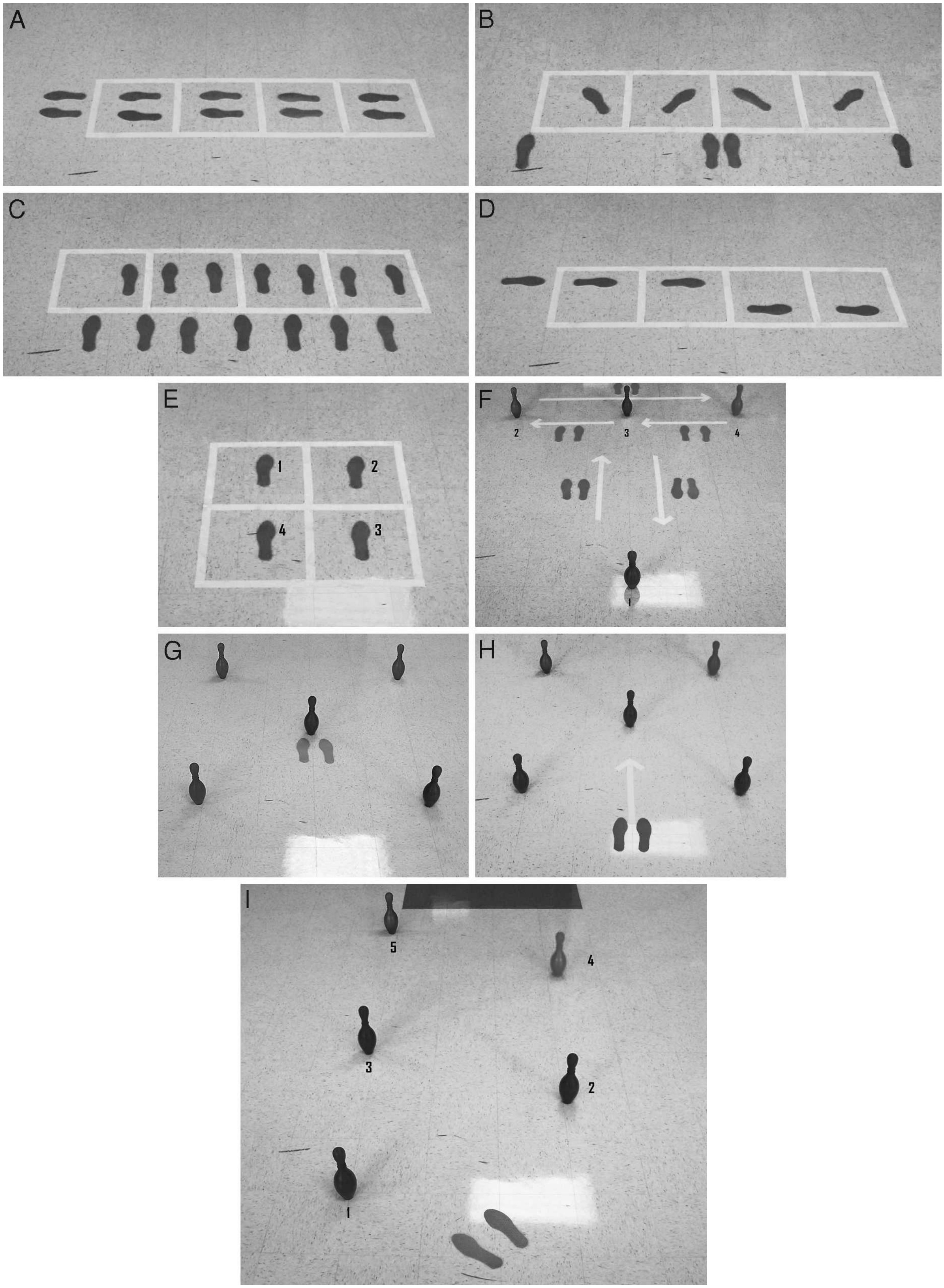

Figure 4. Phase 4 agility drills. A, Backpedal. B, Hip drill. C, Ali-cross. D, Single-leg 2-square hops. E, Square drill with single-leg hop. The hop sequence is given. F, T test. The sequence is given. G, Five-cone drill. H, Four-leaf clover. I, Agility cones. The sequence is given.

her feet in the square consecutively and then placed 1 foot out of the square while moving the other foot to the next square. Each participant began and ended the proagility drill at the pin. For the hexagon test, each participant performed double-leg jumps from the center to the midpoint of the sides, which were 0.6 m long. She hopped clockwise around the hexagon for the first sequence and then counterclockwise for the second sequence. During the square drill with single-leg hop, each participant hopped with the right leg and then with the left leg and followed the same jump pattern as the square drill with double-leg hop in phases 1 and 2. The step sequence for the all crossover with stutter step is shown in Figure 3G. Each participant crossed the left leg over the line by moving the left leg across the right, moved the right leg across the line, and finally performed a stutter step with the left foot. Pins were set 9 m apart for the shuffle box drill.

Exercises performed during phase 4 agility drills included backpedal, hip drill, Ali-cross (scissor kicks), single-leg 2-square hops, square drill with single-leg hop, T test, 5-cone drill, 4-leaf clover, and agility cones (Figure 4). The backpedal drill included every square. For the hip drill, each participant landed in squares with the foot 45° from center. For the square drill with single-leg hop, each participant followed the same jump pattern as in phase 3 and hopped with her right leg and then with her left leg. For the T test, each participant sprinted forward between pins 1 and 3 (9 m apart), shuffled between pins 2 and 4 (9 m apart), and backpedaled between pins 3 and 1. She performed 1-3-2-4-3-1 for the first sequence and 1-3-4-2-3-1 for the second sequence. The sides of the squares in the 5-cone drill were 9 m long. Each participant started at the center pin, sprinted to a corner pin, pivoted 180°, sprinted back to the center, and circled the pin, and she continued this pattern until all pins were reached once. During this drill, each participant pivoted with her right foot for the first sequence and with her left foot for the second sequence. The setup for the 4-leaf clover was identical to the setup for the 5-cone drill. Each participant sprinted to the center pin, sprinted to a corner pin, circled the pin, sprinted to the center, and circled the center pin. She continued this pattern until she reached all pins once. She circled the pins around the right for the first sequence and around the left for the second sequence. Pins were 4.5 m apart for the agility cones drill. Each participant sprinted to the first pin and circled it, sprinted to the second pin and circled it, and continued this pattern until she had circled the last pin and had sprinted across the finish line.

Data Processing

Muscle Activation Processing. We used MotionMonitor software to process EMG data after acquisition. The EMG data from the MVIC and side-step pivot maneuver were passively demeaned and bandpass filtered (10–350 Hz) using a fourth-order, zero-phase lag Butterworth filter. The root mean square of EMG signals taken during a 20-millisecond time constant was calculated to further smooth the data. The MotionMonitor software used a centered root mean square calculation.

Knee Joint Kinematics Processing. Three-dimensional kinematic data of the knee from the side-step pivot maneuver were processed for data analysis. The axes of rotation were specified using a joint coordinate system for each lower extremity segment to describe position and orientation of the segment. The orthogonal axes were arranged so that the z-axis (longitudinal axis) was contained within the lower leg and reflected knee internal and external rotation. The x-axis (medial-lateral axis) was defined as being perpendicular to the sagittal plane, allowing knee flexion. The y-axis (anterior-posterior axis) was designated as the floating axis and was represented by knee valgus-varus motion. The use of the joint coordinate system allowed for analysis of the kinematic data independent of the order in which the rotations were entered into the matrix calculations. Kinematic data were low-pass filtered using a fourth-order, zero-phase lag Butterworth filter at 14.5 Hz.

Ground Reaction Force Processing. Ground reaction force data from the side-step pivot maneuver were processed for data analysis. MotionMonitor software converted analog data to digital data to ground reaction forces. Raw ground reaction force data were used for data analysis.

Synchronization. Kinematic data were sampled at 144 Hz, whereas EMG and ground reaction force data were sampled at 1440 Hz. The kinematic data were time synchronized to the EMG and ground reaction force data and were resampled to 1440 Hz using the MotionMonitor software. Next, data were exported in spreadsheet formats for data analysis.

Data Analysis

Muscle Activation Analysis. We used MATLAB (version 6.1; The MathWorks, Inc, Natick, MA) to compute mean amplitude muscle activity for the preparatory and loading phases while participants performed a side-step pivot maneuver. The preparatory phase was defined as the 50 milliseconds before ground contact, as determined by VGRF. Vertical ground reaction force values exceeding 10 N signified initial foot contact. The loading phase was defined at the time the foot was in contact with the ground. Mean amplitude muscle activity was normalized to MVIC mean amplitude muscle activity. To calculate MVIC mean amplitude muscle activity, the first and last seconds of the MVIC trial were removed from the data to ensure only steady-state results during the MVIC test. Next, the mean activity for each MVIC trial was determined for each muscle. The mean across the 3 MVIC trials was determined and used to normalize the muscle activity data collected during the side-step cutting task for each respective muscle. This normalized value was multiplied by 100. Thus, normalized mean amplitude muscle activation data during the side-step pivot maneuver were expressed as %MVIC.

Analysis of Knee Kinematics. Knee kinematic data were analyzed using MATLAB. Knee flexion angle at the instant of initial ground contact during the side-step pivot maneuver was analyzed. Knee flexion angle at initial ground contact was defined as the angle of knee flexion at the moment when the plant foot first contacted the ground, which was determined through the VGRF. Maximum knee flexion angle during the stance phase of the side-step pivot maneuver was also determined. Finally, knee flexion displacement was calculated from the difference in maximum knee flexion angle during the stance phase of the side-step pivot maneuver and the knee flexion angle at initial ground contact.

VGRF Analysis. Peak VGRF was calculated using MATLAB. Peak VGRF was defined as the maximum value of the VGRF. Body weight was used to normalize peak VGRF data.

Statistical Analysis

The average of the 3 trials was used for data analysis for each dependent variable. The mean, SD, and 95%

Table 1. **Normalized Mean Muscle Activation (Percentage of Maximal Voluntary Isometric Contraction) (Mean ± SD) (95% Confidence Interval)**

Muscle	Pretest Preparatory Phase	Posttest Preparatory Phase	Within-Groups Effect Size Preparatory Phase	Pretest Loading Phase	Posttest Loading Phase	Within-Groups Effect Size Loading Phase
Vastus medialis oblique						
Training group	12.57 ± 12.07 (6.46, 18.68)	14.72 ± 10.15 (9.58, 19.86)	0.20	413.45 ± 197.39 (313.56, 513.34)	322.25 ± 175.44 (233.47, 411.03)	−0.49
Control group	13.27 ± 11.02 (7.70, 18.85)	16.65 ± 20.45 (6.30, 27.00)	0.21	366.86 ± 168.60 (281.54, 452.18)	273.30 ± 168.38 (188.10, 358.51)	−0.56
Between-groups effect size	0.06	0.12		−0.25	−0.28	
Rectus femoris						
Training group	5.90 ± 6.06 (2.83, 8.97)	5.58 ± 4.83 (3.14, 8.02)	−0.06	111.04 ± 49.47 (86.00, 136.07)	115.91 ± 45.56 (92.85, 138.97)	0.10
Control group	6.01 ± 3.52 (4.23, 7.80)	8.75 ± 14.21 (1.56, 15.94)	0.26	111.39 ± 51.41 (85.37, 137.41)	158.16 ± 99.87 (107.62, 208.70)	0.59
Between-groups effect size	0.02	0.30		0.01	0.54	
Medial hamstrings						
Training group	11.65 ± 19.51 (1.78, 21.52)	4.27 ± 2.31 (3.10, 5.44)	−0.53	60.98 ± 22.98 (49.35, 72.61)	103.03 ± 58.63[a,b] (73.36, 132.70)	0.94
Control group	6.44 ± 3.58 (4.63, 8.25)	9.53 ± 12.65 (3.13, 15.93)	0.33	88.53 ± 27.88[c] (74.42, 102.64)	71.20 ± 27.47 (57.30, 85.10)	−0.63
Between-groups effect size	−0.37	0.58		1.07	−0.70	
Lateral hamstrings						
Training group	16.63 ± 25.10 (3.93, 29.33)	5.40 ± 3.01 (3.88, 6.92)	−0.63	150.05 ± 86.76 (106.14, 193.96)	118.10 ± 73.11 (81.10, 155.10)	−0.40
Control group	12.40 ± 21.16 (1.69, 23.11)	7.40 ± 10.97 (1.85, 12.95)	−0.30	133.46 ± 81.23 (92.35, 174.57)	119.20 ± 50.03 (93.88, 144.52)	−0.21
Between-groups effect size	−0.18	0.25		−0.20	0.02	

[a] Training group had greater posttest than pretest loading phase activation.
[b] The posttest loading-phase activation was greater for the training group than for the control group.
[c] The pretest loading-phase activation was greater for the control group than for the training group.

confidence interval (CI) were calculated for all dependent measures. Normalized mean amplitude muscle activity for each EMG-dependent measure was analyzed with separate 2 × 2 × 2 mixed-model, repeated-measures analyses of variance (ANOVAs) with 2 within-groups factors (phase: preparatory, loading; and test: pretest, posttest) and 1 between-groups factor (training, control). Separate 2 × 2 mixed-model, repeated-measures ANOVAs with 1 within-groups factor (pretest, posttest) and 1 between-groups factor (training, control) were calculated for each of the knee flexion kinematic variables (initial ground contact, maximum knee flexion angle, knee flexion displacement) and normalized peak VGRF. We used simple main effects post hoc analyses to examine group differences within phase and test and to examine pretest and posttest differences within group and phase. Effect size for each mean comparison was calculated using the Cohen d.[29] Positive effect size values indicated greater posttest values than pretest values for within-groups comparisons and greater values in the control group than the training group for the between-groups comparisons. We used SPSS (version 13.0 for Windows; SPSS, Inc, Chicago, IL) for statistical analyses. The α level was set a priori at .05.

RESULTS

Means, SDs, and 95% CIs for normalized mean amplitude muscle activity are reported in Table 1; for knee flexion kinematics, Table 2; and for normalized peak VGRF, Table 3.

MH Normalized Mean Amplitude

A group × phase × test interaction was found for MH muscle activation ($F_{1,28} = 15.13$, $P = .001$). Simple main effects testing revealed that the control group had greater MH muscle activation than the training group during the

Table 2. **Knee Flexion Kinematics (Mean ± SD) (95% Confidence Interval)**

Variable	Pretest	Posttest	Within-Groups Effect Size
Initial ground contact flexion			
Training group, °	46.74 ± 12.81 (40.26, 53.22)	49.37 ± 15.66 (41.44, 57.30)	0.18
Control group, °	43.97 ± 12.96 (37.41, 50.53)	46.81 ± 10.12 (41.69, 51.93)	0.24
Between-groups effect size	−0.21	−0.20	
Maximum flexion			
Training group, °	57.51 ± 13.18 (50.84, 64.18)	59.50 ± 13.03 (52.90, 66.10)	0.15
Control group, °	56.52 ± 9.78 (51.57, 61.47)	56.88 ± 8.98 (52.33, 61.42)	0.04
Between-groups effect size	−0.09	−0.23	
Displacement flexion			
Training group, °	10.76 ± 5.78 (7.83, 13.68)	10.14 ± 6.98 (6.61, 13.67)	−0.10
Control group, °	12.55 ± 7.20 (8.91, 16.20)	10.07 ± 4.64 (7.72, 12.42)	−0.41
Between-groups effect size	0.27	−0.01	

Table 3. Normalized Peak Vertical Ground Reaction Force (Multiple of Body Weight) (Mean ± SD) (95% Confidence Interval)

	Pretest	Posttest	Within-Groups Effect Size
Training group	2.36 ± 0.38 (2.16, 2.55)	2.34 ± 0.46 (2.11, 2.57)	−0.05
Control group	2.68 ± 0.43 (2.46, 2.90)	2.66 ± 0.39 (2.46, 2.86)	−0.05
Between-groups effect size	0.79	0.75	

loading phase at pretest ($F_{1,112}$ = 7.53, P = .007), whereas the training group had greater MH muscle activation than the control group during the loading phase at posttest ($F_{1,112}$ = 10.04, P = .002). Simple main effects testing also revealed that posttest MH muscle activation during the loading phase increased 69% from pretest values for the training group ($F_{1,112}$ = 17.53, $P < .001$). We found no difference from pretest to posttest between MH muscle activation for the control group ($F_{1,112}$ = 2.98, P = .09). Other simple main effects testing did not reveal differences between groups within the preparatory phase at pretest ($F_{1,112}$ = 0.27, P = .60) or at posttest ($F_{1,112}$ = 0.27, P = .60). From pretest to posttest, we found no differences within the preparatory phase for the training group ($F_{1,112}$ = 0.54, P = .46) or the control group ($F_{1,112}$ = 0.09, P = .76).

No 2-way interactions were found for phase × test ($F_{1,28}$ = 2.61, P = .12) or phase × group ($F_{1,28}$ = 0.04, P = .85). A test × group interaction ($F_{1,28}$ = 8.17, P = .01) was found. No main effect was found for group ($F_{1,28}$ = 0.04, P = .85) or test ($F_{1,28}$ = 1.43, P = .24). A main effect for phase ($F_{1,28}$ = 164.58, $P < .001$) was found.

LH Normalized Mean Amplitude

No group × phase × test interaction for LH muscle activation ($F_{1,28}$ = 0.10 P = .76) was found. No 2-way interactions were found for phase × test ($F_{1,28}$ = 0.70, P = .41), phase × group ($F_{1,28}$ = 0.12, P = .73), or test × group ($F_{1,28}$ = 0.44, P = .51). No main effect for group ($F_{1,28}$ = 0.15, P = .70) or test ($F_{1,28}$ = 2.96, P = .10) was found. A main effect for phase ($F_{1,28}$ = 154.32, $P < .001$) was found, indicating that the loading-phase mean collapsed across groups and tests was greater than the preparatory-phase mean collapsed across groups and tests.

VMO Normalized Mean Amplitude

No group × phase × test interactions were found for VMO muscle activation ($F_{1,28}$ = 0.01, P = .94). However, a phase × test interaction ($F_{1,28}$ = 14.30, P = .001) was found, indicating that VMO muscle activation collapsed across groups decreased from pretest to posttest during the loading phase. No 2-way interactions were found for phase × group ($F_{1,28}$ = 0.72, P = .40) or test × group ($F_{1,28}$ = 0.001, P = .98). No main effect for group ($F_{1,28}$ = 0.58, P = .45) was found. Main effects for test ($F_{1,28}$ = 10.67, P = .003) and phase ($F_{1,28}$ = 129.35, $P < .001$) were found.

RF Normalized Mean Amplitude

No group × phase × test interactions were found for RF muscle activation ($F_{1,28}$ = 2.59, P = .12). No 2-way interactions were found for phase × test ($F_{1,28}$ = 4.16, P = .05), phase × group ($F_{1,28}$ = 1.04, P = .32), or test × group ($F_{1,28}$ = 2.63, P = .12). No main effect for group ($F_{1,28}$ = 1.16, P = .29) or test ($F_{1,28}$ = 3.80, P = .06) was found. A main effect for phase ($F_{1,28}$ = 148.97, $P < .001$) was found, indicating that the loading-phase mean collapsed across groups and tests was greater than the preparatory-phase mean collapsed across groups and tests.

Knee Flexion Kinematics

No group × test interaction for knee flexion at initial ground contact was found ($F_{1,28}$ = 0.002, P = .96). We did not find a main effect for group ($F_{1,28}$ = 0.41, P = .53) or for test ($F_{1,28}$ = 1.43, P = .24). No group × test interaction for maximum knee flexion angle was found ($F_{1,28}$= 0.17, P = .68). We did not find a main effect for group ($F_{1,28}$ = 0.24, P = .63) or for test ($F_{1,28}$ = 0.36, P = .56). No group × test interaction for knee flexion displacement was found ($F_{1,28}$ = 0.48, P = .50). We did not find a main effect for group ($F_{1,28}$ = 0.22, P = .64) or for test ($F_{1,28}$ = 1.35, P = .26).

Normalized Peak VGRF

No group × test interaction for normalized peak VGRF ($F_{1,28}$ = 0.68, P = .42) was found. No main effect for test ($F_{1,28}$ = 1.20, P = .28) was found. Finally, no main effect for group ($F_{1,28}$ = 3.98, P = .06) was found.

DISCUSSION

We hypothesized that agility training would increase hamstrings activation during the side-step pivot. Our most important finding was that the agility training program increased MH activation during the loading phase of the side-step pivot maneuver. However, agility training did not affect LH activation. A low level of hamstrings muscle activation might be a predisposing factor to ACL sprain in females, and several researchers[5,11,13,16–18] have suggested that increased hamstrings activation might be beneficial in preventing ACL sprain by limiting the amount of excessive anterior tibial translation during functional movements. The results of our study have clinical relevance because improved MH activation after agility training might help limit excessive strain on the ACL during functional activities, possibly decreasing ACL injury in physically active females.

Hirokawa et al[30] indicated that adequate knee flexion angles are required for hamstrings activation to prevent excessive anterior tibial translation. Consequently, our agility training exercises required participants to maintain a flexed position at the hips, knees, and ankles. Additionally, the agility training implemented in our study focused on quick changes of direction while staying in a functional flexed position. The repetition of staying in a functional flexed position during 6 weeks of agility training might have influenced MH activation. Another possible reason for increased MH activation was that, during the last 2 phases of training, side-step pivoting was simulated in almost all exercises of the training program. Participants were required to stay low and approach cones as if attempting a side-step pivot maneuver, which may have facilitated an increase in MH activation.

Improved MH activation might have importance in limiting anterior tibial translation. Wojtys et al[18] reported that agility training has improved hamstrings muscle activation by decreasing cortical response times to anterior tibial translation joint perturbations. Hurd et al[13] recently reported that perturbation training improved MH and LH activation, and they suggested that increased hamstrings activation might limit excessive anterior tibial translation during functional activities. Therefore, we contend that the increased MH activation associated with agility training might have implications for decreasing excessive anterior tibial translation and preventing ACL sprain in females.

Agility training did not improve LH activation, and we speculate that joint motion associated with the side-step pivot maneuver might have affected our results. Neptune et al[31] suggested that the LH function to resist excessive internal tibial rotation during a side-step pivot and the MH function to resist excessive external tibial rotation. Increased MH activation might have been due to the MH resisting the anterolateral rotary tibial shift as participants performed the side-step pivot. Participants completing the training might have improved the ability of the MH to activate and resist this joint motion. Increased LH activation might not be needed to resist this joint motion. In future research, investigators should examine the effects of agility training on hamstrings activation during other functional movements associated with ACL injury.

Our agility training did not affect muscle activation during the preparatory phase. This finding suggests that agility training does not influence motor programs related to quadriceps and hamstrings muscle activation. Agility training influences MH activation during ground contact, suggesting that MH activation might result from reflexive activation or automatic activation. The focus of our study was to determine if muscle activation could be increased, and we did not design the study to establish if the muscle activation during ground contact was reflexive, automatic, or preprogrammed.

Quadriceps activation was not affected by agility training. Ciccotti et al[23] reported that the decreased VMO and vastus lateralis activation in participants with ACL-deficient knees was accompanied by increased LH activation during functional movements. Ideally, the VMO and RF activation should have only decreased in the training group because participants performing the training increased MH muscle activation. However, VMO activation decreased in the training and control groups by 22% and 26%, respectively. We are not sure of reasons for this decreased VMO activation in both groups. Perhaps participants developed familiarity with the side-step pivot maneuver from pretest to posttest sessions because they performed pretests before beginning their competitive basketball seasons and performed posttests 6 weeks into their seasons. In addition, participants might have learned to decrease VMO activation when they performed the side-step pivot maneuver after having performed this maneuver throughout their competitive seasons.

Our results indicate that knee flexion kinematics and normalized peak VGRF did not change from pretest to posttest sessions, suggesting that the increased MH activation in the training group and the decreased VMO activation in both groups were not influenced by kinematics or peak VGRF. Participants performed exercises in a functional flexed position, but our program did not address increasing knee flexion angles throughout the full 6-week program. However, addressing knee flexion during agility training might have implications for improving knee joint stability. Researchers[3–11] have suggested that keeping females out of an upright position during functional movements might help decrease ACL sprain. Additionally, researchers[5,11] have suggested that pivoting with a greater amount of knee flexion range of motion might allow a distribution of forces on the ACL for a longer period and limit the amount of stress. Perhaps emphasizing knee flexion for a longer period during agility training would allow participants to increase the amount of knee flexion during the side-step pivot.

CONCLUSIONS

Our 6-week agility training program increased MH activation in women participating in intramural basketball. However, agility training did not affect LH, VMO, or RF activation. Investigators should use this agility training program in a prospective study and examine injury rates for several years to determine if this program is useful for decreasing ACL injuries in female basketball players.

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