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Instruction and Jump-Landing Kinematics in College-Aged Female Athletes Over Time

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Context: Instruction can be used to alter the biomechanical movement patterns associated with anterior cruciate ligament (ACL) injuries.

Objective: To determine the effects of instruction through combination (self and expert) feedback or self-feedback on lower extremity kinematics during the box–drop-jump task, running–stop-jump task, and sidestep-cutting maneuver over time in college-aged female athletes.

Design: Randomized controlled clinical trial.

Setting: Laboratory.

Patients or Other Participants: Forty-three physically active women (age = 21.47 ± 1.55 years, height = 1.65 ± 0.08 m, mass = 63.78 ± 12.00 kg) with no history of ACL or lower extremity injuries or surgery in the 2 months before the study were assigned randomly to 3 groups: self-feedback (SE), combination feedback (CB), or control (CT).

Intervention(s): Participants performed a box–drop-jump task for the pretest and then received feedback about their landing mechanics. After the intervention, they performed an immediate posttest of the box–drop-jump task and a running–stop-jump transfer test. Participants returned 1 month later for a retention test of each task and a sidestep-cutting maneuver. Kinematic data were collected with an 8-camera system sampled at 500 Hz.

Main Outcome Measure(s): The independent variables were feedback group (3), test time (3), and task (3). The dependent variables were knee- and hip-flexion, knee-valgus, and hip- abduction kinematics at initial contact and at peak knee flexion.

Results: For the box–drop-jump task, knee- and hip-flexion angles at initial contact were greater at the posttest than at the retention test ($P < .001$). At peak knee flexion, hip flexion was greater at the posttest than at the pretest ($P = .003$) and was greater at the retention test than at the pretest ($P = .04$); knee valgus was greater at the retention test than at the pretest ($P = .03$) and posttest ($P = .02$). Peak knee flexion was greater for the CB than the SE group ($P = .03$) during the box–drop-jump task at posttest. For the running–stop-jump task at the posttest, the CB group had greater peak knee flexion than the SE and CT ($P \leq .05$).

Conclusions: Our results suggest that feedback involving a combination of self-feedback and expert video feedback with oral instruction effectively improved lower extremity kinematics during jump-landing tasks.

Key Words: augmented feedback, technique instruction, box-drop jump, running-stop jump, sidestep-cutting maneuver

Key Points

- The use of oral and combo video feedback improved lower extremity biomechanics during jump-landing tasks.
- Combined self- and expert video feedback with oral instruction after a box–drop-landing task improved peak knee-flexion angles.
- Combining self- and expert video feedback is an easy, effective tool for changing lower extremity kinematics.
- The use of oral and video feedback for a box–drop-jump task did not transfer to improved lower extremity biomechanics during a sidestep-cutting maneuver.

An increasing number of anterior cruciate ligament (ACL) injuries have occurred in various sports, including basketball, soccer, and volleyball, over the past 15 years.[1–4] A noncontact mechanism accounts for approximately 72% of all ACL injuries and typically occurs during activities that include deceleration, jump landing, and sidestep cutting.[5–8] Anterior cruciate ligament injuries carry short-term consequences, such as surgical repair, extensive rehabilitation, and a loss of athletic identity, and serious long-term consequences, such as osteoarthritis and joint laxity.[9–11] A patient with a history of knee injury during adolescence has a 3 times greater risk of developing osteoarthritis by age 65 years than a patient without this history.[10] Several potential risk factors have been identified as contributors to noncontact ACL injuries, including biomechanical risk factors such as muscular strength, body movement and forces, skill level, muscular activation, and neuromuscular control.[6,7]

Researchers[9,12–17] frequently have studied lower extremity kinematics during activities, such as landing or decelerating, that place the participant at risk for injury to find alignments that might put the body in an at-risk position. Decreased knee and hip flexion, increased knee valgus, increased hip internal rotation, and decreased hip abduction are common lower extremity alignments seen during noncontact ACL injuries and are considered to be at-risk body positions.[9,11,13] For example, decreased knee-flexion angles while landing cause the hamstrings to less effectively protect the ACL from the anterior tibial translation caused by the quadriceps exerting maximal anterior shear force at the small knee-flexion angle.[6,7,18–20] Therefore, programs designed to improve strength and balance and to instruct athletes in proper lower extremity alignment during jump-landing activities often are used to decrease the risk of ACL injury.[21–25]

These injury-prevention programs have succeeded in demonstrating that an athlete's biomechanics can be altered. The focus of most prevention programs, whether they are based on plyometrics, balance, or instruction, is on improving landing or decelerating technique and incorporates oral and visual feedback.[26–33] These types of feedback are considered augmented feedback because they are from an external source that is provided to the learner.[34] Augmented feedback can be divided into 3 different categories: knowledge of results, knowledge of performance, and biofeedback.[34,35] Many injury-prevention programs frequently use knowledge of performance feedback, which includes information about the characteristics of a movement that lead to prescribed outcomes.[35]

Augmented feedback recently has been used to decrease the biomechanical risk factors associated with ACL injuries.[28,36–39] For example, oral and video feedback decrease ground reaction forces from a box–drop-landing, and the combination of self-feedback and expert video feedback (combo feedback) improves knee-flexion angles at peak knee flexion during a running–stop-jump task.[28,36,37] However, no one knows if using a simple clinical feedback tool will improve biomechanical risk factors associated with jump-landing activities over time and which form of feedback (self or combo) is most effective. In addition, no one knows if feedback on a simple jump-landing task will transfer to an improvement in more sport-specific tasks. Therefore, our primary purpose was to determine whether instruction (self or combo) would affect box-drop, running–stop-jump, and sidestep-cutting maneuver lower extremity kinematics (knee flexion, knee valgus, hip flexion, hip abduction) over time in healthy college-aged female athletes. We hypothesized that combo feedback would improve lower extremity kinematics (eg, increased knee flexion, decreased knee valgus, and increased hip abduction) better than self-feedback or no feedback. Our secondary purpose was to determine if feedback related to the box–drop-jump task would transfer to an improvement in running–stop-jump task and sidestep-cutting maneuver lower extremity kinematics. We hypothesized that combo feedback for the box–drop-jump technique would improve lower extremity kinematics for the running–stop-jump task and sidestep-cutting maneuver.

METHODS

Study Design

Three sport tasks (box–drop-jump task, running–stop-jump task, and sidestep-cutting maneuver) were analyzed separately. A 3 $\times$ 3 (feedback type $\times$ time) between-subjects and within-subject repeated-measures design was used for the box–drop-jump task. Feedback consisted of self, combo, and control groups. Time consisted of pretest, immediate posttest, and retention test. A 3 $\times$ 2 (feedback type $\times$ time) between-subjects and within-subject repeated-measures design was used for the running–stop-jump task. Feedback groups were the same as for the box–drop-jump task, and time was posttest and retention test. Finally, a 1-way design with 3 levels of feedback was used to investigate the sidestep-cutting maneuver at the time of the other retention tests. The dependent variables were the following 4 kinematic variables: knee flexion, knee valgus, hip flexion, and hip abduction measured in degrees at initial contact and peak knee flexion.

Participants

A convenience sample of 46 healthy female recreational and varsity athletes between the ages of 18 and 25 years (age = 21.47 $\pm$ 1.55 years, height = 1.65 $\pm$ 0.08 m, mass = 63.78 $\pm$ 12.00 kg) voluntarily participated in the study. Adequate sample size was calculated a priori based on data from previous studies[36,37] focusing on the effects of feedback on lower extremity biomechanics. To achieve 80% statistical power with an α level of .05, a sample of convenience of 46 participants was deemed adequate. Inclusion criteria required that each participant be physically active at least 3 times per week for a minimum of 20 minutes and have no history of ACL injury or reconstructive surgery. The following criteria excluded a person from participating in the study: lower extremity injury in the 2 months before the study that limited her from participating in activity for more than 1 day, self-reported lower extremity instability at the time of the study, any lower extremity surgery within the 2 years before the study, and a history of jump-landing technique training. Each participant provided written informed consent, and the study was approved by the Old Dominion University Institutional Review Board.

Instrumentation

Kinematic data were obtained using an 8-camera motion-capture system (VICON MXF40; VICON Motion Systems Ltd, Oxford, UK), and 2 force plates (model 4060NC; Bertec Corporation, Columbus, OH) were used to collect kinetic data relating to ground reaction forces. These were used to determine the point at which initial contact occurred. Both instruments had a sampling rate of 500 Hz.

A modified Helen Hayes marker set for the lower extremity was used.[40,41] A standing trial was obtained. The static trial was used to create a lower extremity kinematic model and quantify the motion of the hip, knee, and ankle joints. Visual 3D (C-motion, Rockville, MD) was used to create the model for each participant. Kinematic and kinetic data were low-pass filtered with a 25-Hz cutoff frequency through a fourth-order Butterworth zero-lag filter based on a power spectrum analysis.

All of the pretest and posttest box-drop trials also were recorded on 2 digital mini-DV camcorders (model DCR HC40; Sony Electronics, Inc, San Diego, CA). The sagittal-view camera was placed on the side of each participant's dominant lower extremity, and the frontal-view camera was

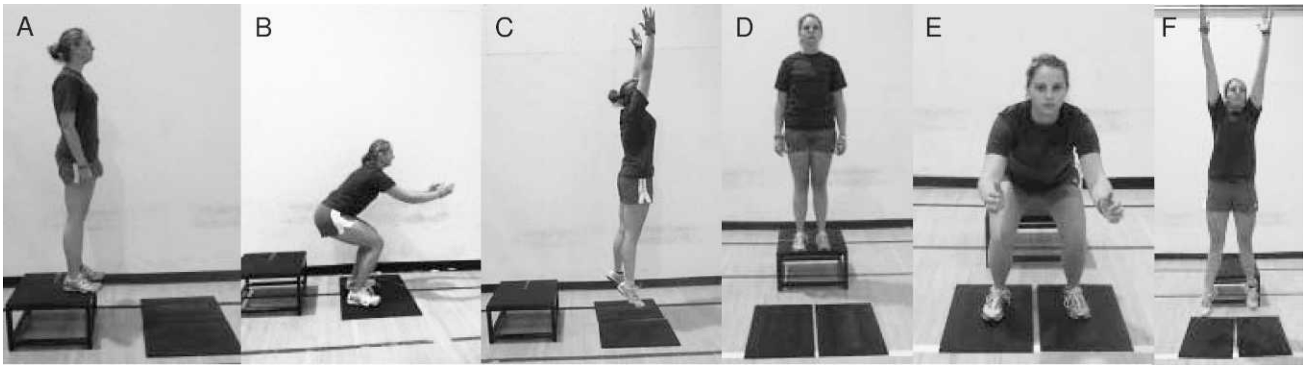

Figure 1. Box–drop-jump technique from, A–C, sagittal and, D–F, frontal views.

placed at the end of the runway facing the force plates. The approach speed for both the running–stop-jump task and the sidestep-cutting maneuver was monitored with a Speed Trap I (Brower Timing Systems, Draper, UT) timing system. The approach speeds for sidestep-cutting maneuvers typically are between 5.5 m/s and 6.5 m/s in a gamelike situation.[15] However, given the restriction of the runway length, all participants were required to have an approach speed of at least 3 m/s for all trials. The average speed for the running–stop-jump task was 3.33 $\pm$ 0.24 m/s, and the average speed for the sidestep-cutting maneuver was 3.61 $\pm$ 0.40 m/s.

Experimental Procedures

Participants reported to the Motion Analysis Laboratory for testing. They were required to wear spandex shorts and a sports bra. All participants wore the running shoes in which they regularly trained. Prescreening measurements included height, mass, and anatomic measurements (leg length, knee width, and ankle width) and were taken by the same researcher (J.E.). They also reported their dominant lower extremities at this time, which also were used as the measured limbs. The *dominant lower extremity* was defined as the extremity the participant would use to kick a ball as far as possible.[1,19,42] All participants were right-limb dominant. After these measurements, participants were allowed 5 minutes to warm up on the bicycle and 5 minutes of self-directed stretching. Reflective markers then were placed on specific bony landmarks.

After the markers were placed on the participant, a static trial was conducted. Next, participants performed 3 practice trials of the box–drop-jump task. The box–drop-landing task is a tool commonly used to evaluate landing biomechanics.[19,43,44] This task consisted of participants standing on a box placed 30 cm from the force plates and 30 cm high. They leaned forward with both feet at the edge of the box, fell forward off the box, landed with each foot on the corresponding force plate, and immediately jumped straight up in the air to achieve maximal jump height. When landing, each foot had to land on the corresponding force plate again (Figure 1).[45,46] Trials were discarded if both feet were not on the corresponding force plates or the participant lost her balance. Immediately after the practice trials, they performed 5 successful trials. After performing the box–drop-jump trials, they received the intervention portion of the test. Each participant was assigned randomly to 1 of 3 instructional groups: self (n = 15), combo (n = 15), or control (n = 13). The assignment was accomplished by instructing each participant to select an envelope labeled A, B, or C, which corresponded to a different feedback group. Each feedback group had to have 15 participants; therefore, after all slots were filled in 1 group, that group no longer could be selected. This process ensured that participants were assigned randomly to feedback groups.

Intervention

After participants were assigned randomly to a group, the combo and self groups received feedback on their box–drop-jump trials. The control group received no feedback and was given the allotted time to read a magazine. A maximum of 10 minutes was allowed for all groups. The participants in the combo and self groups viewed 4 trials from both the frontal and sagittal views. The self-feedback group viewed 4 of the 5 trials of the box–drop-jump task that they just performed, whereas the combo feedback group viewed 2 trials of an expert performing a box–drop-jump task and the first 2 trials of their own performance of the box–drop-jump task. During the viewing of the combo and self groups' trials, the investigator (J.E.) produced a freeze frame of the film at roughly peak knee flexion to allow adequate opportunity to view the trials; the same investigator provided feedback for all participants. To analyze all trials, the participants and researcher reviewed a standardized feedback tool, which focused on ankle, knee, and hip alignment and angles. The Landing Error Scoring System (LESS) commonly is used as a clinical motion-assessment tool to identify errors in jump-landing technique and has been shown to be valid and reliable.[47,48] We used the LESS criteria as the points of discussion in the feedback tool, which consisted of a grading sheet used by the participants in the combo and self groups (Figure 2). Participants circled *yes* or *no* to indicate whether they met the stated criterion for each trial viewed; a majority of *yes* responses was desired, whereas all responses of *no* equaled a poor jump-landing technique. The instructor provided both oral and visual feedback to the participants by discussing the checklist criteria and pointing out proper and improper technique on the television screen for all 4 trials, frontal and sagittal, viewed.[36]

Immediate Posttest

At the end of the allotted 10 minutes, participants began the immediate posttest. They also were allowed 2 practice

Video Feedback
Self/Combo

Front View	Trial 1	Trial 2	Trial 3	Trial 4
1. Toe to heel landing	Y/N	Y/N	Y/N	Y/N
2. Feet land at same time	Y/N	Y/N	Y/N	Y/N
3. Stance shoulder width apart	Y/N	Y/N	Y/N	Y/N
4. Knees over midfoot (no valgus)	Y/N	Y/N	Y/N	Y/N
5. No side bending	Y/N	Y/N	Y/N	Y/N
Side View				
1. Toe to heel landing	Y/N	Y/N	Y/N	Y/N
2. Feet land at same time	Y/N	Y/N	Y/N	Y/N
3. Knee angle > 30°	Y/N	Y/N	Y/N	Y/N
4. Trunk in front of hips	Y/N	Y/N	Y/N	Y/N
5. Knee doesn't go farther in than great toe	Y/N	Y/N	Y/N	Y/N

Key Points
- Land with your knee bent
- Land with your trunk bent
- Keep knees over toes

Figure 2. The video-feedback standardized tool.

trials of the box–drop-jump task. The participants then performed 5 trials of the box–drop-jump task with a 30-second rest between trials. After the data were collected, the participants performed an initial transfer test of a running–stop-jump task. The running–stop-jump task is an athletic maneuver frequently performed in various sports.[49–51] Participants had an approach run and then a 2-footed landing, with each foot landing on the corresponding force plate. The landing was followed by an immediate takeoff (vertical jump) for maximum height and landing back onto the force plates (Figure 3).[43] A trial was discarded if the participant did not reach a speed greater than 3 m/s on the approach run, both feet did not land on their corresponding force plates, or the participant took an extra step forward or backward. The transfer test was designed to evaluate if teaching proper landing mechanics of a box–drop-jump task would result in improved biomechanics in other sport-specific tasks. After we gave instructions, participants were allowed 2 practice trials and 5 recorded trials with a 30-second rest between trials. For all trials, we recorded the running approach speed of all participants. At the end of testing, they were instructed to report to the laboratory after 1 month for a retention test.

1-Month Retention Test

Participants returned to the laboratory at least 1 month (mean = 5.49 ± 0.67 weeks) after the original test date for a retention test. Each participant was required to wear the same type of clothing and the same shoes in which she originally was tested. The same set of procedures as the original test was performed. The original set of instructions and explanation of the box–drop-jump task also were read to them. They were allowed 2 practice trials, and 5 trials with a 30-second rest between trials were recorded. After the box–drop-jump trials had been collected, the participants performed the initial transfer test (running–stop-jump task) originally performed during the immediate posttest session. They were given 2 practice trials and performed 5 trials with a 30-second rest between trials, and we recorded all running approach speeds. The running–stop-jump task was used as both an initial transfer test and a retention test. After performing the running–stop-jump task, the participants performed a sidestep-cutting maneuver as a delayed transfer test. A sidestep-cutting maneuver is a regularly performed task for many athletes, particularly soccer and basketball players, in games and practices.[52–55] The sidestep-cutting maneuver that the participants performed in the laboratory was between 35° and 55°, which put them

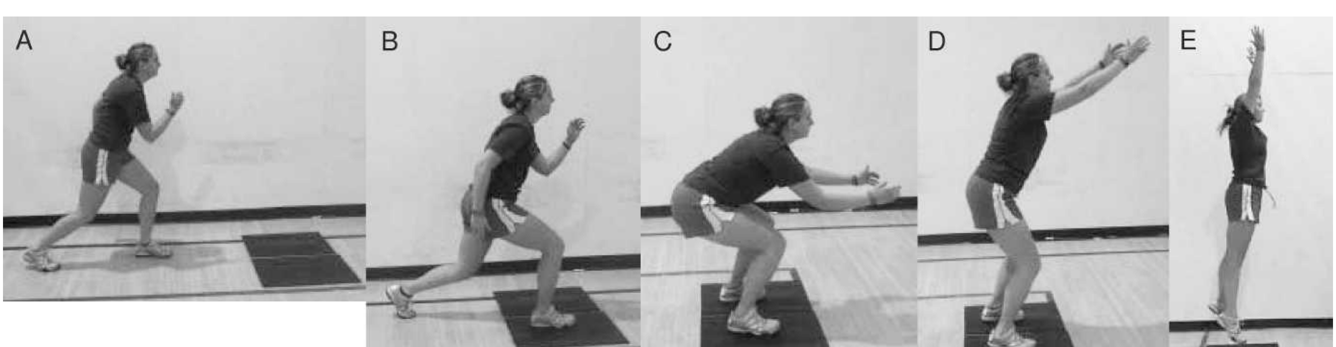

Figure 3. A–E. Running–stop-jump technique from the sagittal view.

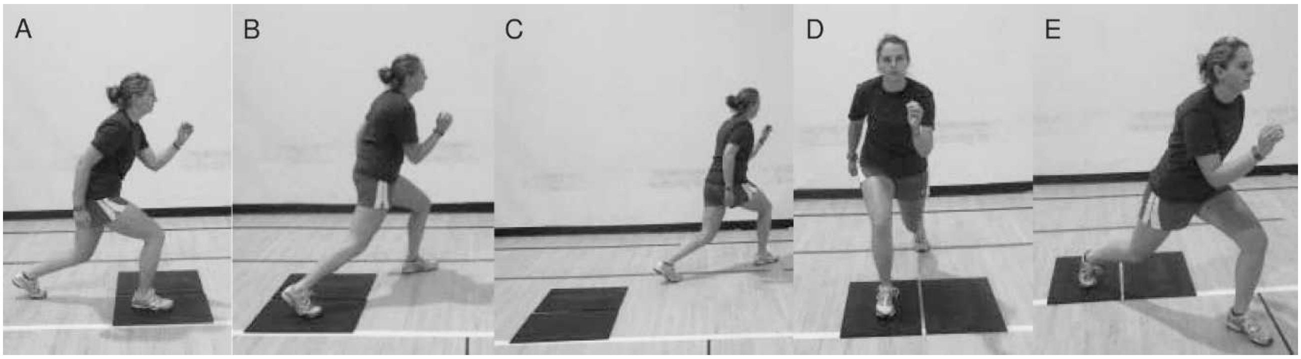

Figure 4. Sidestep-cutting-maneuver technique from the, A–C, sagittal and, D and E, frontal views.

approximately at 45°. This angle was constrained by the platform on which they performed the task. This task consisted of a running approach, contact of the dominant lower extremity with the corresponding force plate, and a change of direction to the nondominant side. Participants were instructed to follow the sidestep-cutting maneuver with a few steps (Figure 4).[15,56] Trials were discarded if the participant did not have a running approach speed greater than 3 m/s, her dominant foot did not land on the force plate, or she lost her balance. After instructions were given, participants were allowed 2 practice trials, and 5 trials with a 30-second rest between trials were performed. For all trials, running approach speeds also were recorded.

Statistical Analysis

All data were reduced using MATLAB (version 6.1; The MathWorks, Inc, Natick, MA) software with a custom-made model to export the dependent variables into an Excel 2007 (Microsoft Corporation, Redmond, WA) spreadsheet. The 5 trials were averaged and exported into SPSS (version 16.0; IBM Corporation, Armonk, NY) for data analysis. All analyses were performed during the stop-jump phase. The average of all 5 trials was used to compare kinematic variables over time. For all 3 tasks, the 4 lower extremity angles at both initial contact and peak knee flexion were analyzed separately. Three sport tasks (box–drop-jump task, running–stop-jump task, and sidestep-cutting maneuver) were analyzed separately. A 3 × 3 (feedback type × time) between-subjects and within-subject repeated-measures analysis of variance (ANOVA) was used for the box–drop-jump task. Feedback included self, combo, and control groups. Time included pretest, immediate posttest, and retention test. A 3 × 2 (feedback type × time) between-subjects and within-subject repeated-measures ANOVA was used for the running–stop-jump task. Feedback groups were the same as for the box–drop-jump task, and time included posttest and retention test. Finally, a 1-way ANOVA with 3 levels of feedback was used to investigate the sidestep-cutting maneuver at the time of the other retention tests. The dependent variables included the following 4 kinematic variables: knee flexion, knee valgus, hip flexion, and hip abduction measured in degrees at initial contact and peak knee flexion. We used post hoc Tukey tests with Bonferroni adjustment for multiple comparisons to analyze main effects and interactions and to assess differences between feedback groups where appropriate. The α level was set a priori at .05.

RESULTS

Descriptive statistics for the box–drop-jump task and running–stop-jump task with means, standard deviations, and 95% confidence intervals are presented in Tables 1 and 2, respectively. No interactions were noted for any of the dependent variables ($P > .05$); only main effects are reported in this section.

Box–Drop-Jump Task Over Time (Pretest to Immediate Posttest to Retention Test)

For the box–drop-jump task, we found a difference among feedback groups at pretest for knee flexion at initial contact ($F_{2,40} = 6.68$, $P = .003$) and for hip flexion at initial contact ($F_{2,40} = 3.40$, $P = .04$). The post hoc Tukey test revealed that during the pretest, knee flexion at initial contact was greater for the combo feedback group than for the self-feedback group ($P = .003$, Cohen d = 0.94) and control group ($P = .049$, Cohen d = 0.67). It also revealed that during the pretest, hip flexion at initial contact was greater for the combo feedback group than the self-feedback group ($P =.03$, Cohen d = 0.75). Because both knee and hip flexion at initial contact during the pretest box–drop-jump task were different among feedback groups, the corresponding variables were used as a covariate in 2 separate 2 (test time) × 3 (feedback) repeated-measures ANOVAs to account for this pretest difference, whereas the remaining variables were analyzed using 6 separate 3 (test time) × 3 (feedback) repeated-measures ANOVAs. We found that at initial contact, knee flexion during the box–drop-jump task was greater during the posttest than during the retention test ($F_{1,39} = 13.50$, $P = .001$, Cohen d = 0.29). Hip flexion at initial contact was greater at the posttest than at the retention test ($F_{1,39} = 15.57$, $P < .001$, Cohen d = 0.19).

We found a main effect for peak knee flexion during the box–drop-jump task ($F_{2,40} = 4.15$, $P = .02$). The post hoc Tukey test revealed that peak knee flexion was greater for the combo feedback group than for the self-feedback group at posttest ($P = .03$, Cohen d = 0.61). At peak knee flexion, we observed a main effect of test time for knee flexion ($F_{2,80} = 3.29$, $P = .043$). Posttest was greater than pretest time ($P = .04$, Cohen d = 0.27). In addition, peak knee flexion was greater at the posttest than at the retention test ($P = .05$, Cohen d = 0.24).

A main effect of test time for knee valgus at peak knee flexion during the box–drop-jump task was found ($F_{1.20,48.15} = 6.10$, $P = .01$). Knee valgus at peak knee

Table 1. Descriptive Statistics for the Box–Drop-Jump Task

	Pretest		Posttest		Retention test		Time		Feedback	
Box-Drop-Jump Task	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	*P* Value	*F* Value	*P* Value	*F* Value
Initial contact										
Knee flexion (−)/extension (+), °										
Self-feedback group	−17.34 ± 5.34	−20.29, −14.38	−17.17 ± 5.52	−20.23, −14.11	−17.02 ± 5.53	−20.08, −13.96	.001[b]	13.50	.84	0.17
Combo feedback group[a]	−28.72 ± 12.11	−35.42, −22.01	−28.55 ± 11.34	−34.83, −22.27	−22.99 ± 6.96	−26.85, −19.14				
Control group	−20.62 ± 7.16	−24.95, −16.30	−21.65 ± 9.27	−27.25, −16.05	−18.19 ± 8.06	−23.06, −13.32				
Knee valgus (−)/varus (+), °										
Self-feedback group	−2.34 ± 2.72	−3.85, −0.83	−1.98 ± 2.44	−3.33, −0.63	−1.75 ± 2.59	−3.18, −0.31	.90	0.06	.54	0.62
Combo feedback group[a]	−3.61 ± 4.66	−6.19, −1.03	−3.38 ± 4.41	−5.82, −0.94	−3.09 ± 5.59	−6.19, 0.01				
Control group	−1.68 ± 4.09	−4.16, 0.79	−2.31 ± 4.22	−4.86, 0.24	−2.43 ± 4.08	−4.89, 0.04				
Hip flexion, °										
Self-feedback group	36.29 ± 7.39	32.20, 40.38	37.99 ± 8.52	33.27, 42.71	38.09 ± 5.13	35.25, 40.93	<.001[b]	15.57	.57	0.59
Combo feedback group[a]	44.81 ± 11.40	38.50, 51.12	44.26 ± 11.05	38.14, 50.37	39.33 ± 7.49	35.18, 43.47				
Control group	40.51 ± 7.24	36.14, 44.89	40.52 ± 7.01	36.28, 44.75	40.24 ± 8.97	34.82, 45.66				
Hip abduction (−)/adduction (+), °										
Self-feedback group	−3.87 ± 3.20	−5.64, −2.09	−4.40 ± 3.56	−6.37, −2.43	−5.01 ± 3.49	−6.95, −3.08	.32	1.15	.82	0.20
Combo feedback group[a]	−4.07 ± 4.32	−6.46, −1.68	−5.16 ± 2.89	−6.76, −3.56	−5.13 ± 3.67	−7.16, −3.09				
Control group	−5.43 ± 4.95	−8.42, −2.43	−5.73 ± 4.35	−8.35, −3.10	−4.57 ± 3.57	−6.73, −2.41				
Peak knee flexion										
Knee flexion (−)/extension (+), °										
Self-feedback group	−80.71 ± 6.25	−84.17, −77.25	−84.19 ± 7.00	−88.07, −80.31	−82.82 ± 8.29	−87.42, −78.23	.04[b]	3.29	.02[b]	4.15
Combo feedback group[a]	−88.07 ± 12.60	−95.05, −81.09	−95.18 ± 14.59	−103.26, −87.10	−89.83 ± 14.73	−97.99, −81.68				
Control group	−81.85 ± 14.71	−90.74, −72.96	−81.42 ± 12.50	−88.98, −73.87	−78.92 ± 10.49	−85.27, −72.58				
Knee valgus (−)/varus (+), °										
Self-feedback group	0.81 ± 10.33	−4.91, 6.53	1.77 ± 8.89	−3.15, 6.69	−1.62 ± 11.91	−8.22, 4.98	.01[b]	6.10	.99	0.10
Combo feedback group[a]	0.63 ± 9.07	−4.39, 5.66	2.67 ± 10.21	−2.99, 8.32	−2.00 ± 14.73	−10.15, 6.16				
Control group	2.82 ± 8.95	−2.59, 8.23	2.25 ± 8.85	−3.10, 7.60	−2.70 ± 8.55	−7.86, 2.47				
Hip flexion, °										
Self-feedback group	73.45 ± 10.30	67.75, 79.16	79.51 ± 10.46	73.72, 85.30	80.01 ± 10.61	74.13, 85.88	.004[b]	6.04	.34	1.12
Combo feedback group[a]	79.73 ± 13.82	72.08, 87.39	86.35 ± 13.10	79.09, 93.61	82.44 ± 11.87	75.87, 89.02				
Control group	77.24 ± 11.87	70.07, 84.42	76.69 ± 11.48	69.75, 83.62	79.19 ± 12.42	71.69, 86.70				
Hip abduction (−)/adduction (+), °										
Self-feedback group	−3.29 ± 5.19	−6.17, −0.42	−5.81 ± 4.97	−8.56, −3.06	−6.74 ± 7.59	−10.94, −2.53	<.001[b]	10.72	.69	0.37
Combo feedback group[a]	−3.42 ± 5.31	−6.36, −0.48	−7.57 ± 4.70	−10.17, −4.97	−7.01 ± 4.48	−9.49, −4.53				
Control group	−6.16 ± 8.69	−11.41, −0.91	−7.33 ± 9.09	−12.82, −1.83	−8.02 ± 6.21	−11.77, −4.26				

Abbreviation: CI, confidence interval.

[a] The combination feedback group received self-feedback and expert video feedback.

[b] Indicates difference.

Table 2. Descriptive Statistics for the Running–Stop-Jump Task

Running–Stop-Jump Task	Posttest		Retention Test		Time		Feedback	
	Mean ± SD	95% CI	Mean ± SD	95% CI	*P* Value	*F* Value	*P* Value	*F* Value
Initial contact								
Knee flexion (−)/extension (+), °								
Self-feedback group	−25.51 ± 10.35	−31.24, −19.77	−32.98 ± 15.04	−41.31, −24.65	.51	0.43	.33	1.14
Combo feedback group[a]	−41.21 ± 17.86	−51.11, −31.32	−30.53 ± 15.17	−38.93, −22.13				
Control group	−33.30 ± 15.93	−42.93, −23.68	−31.00 ± 15.16	−40.16, −21.84				
Knee valgus (−)/varus (+), °								
Self-feedback group	−3.46 ± 4.19	−5.78, −1.14	0.58 ± 5.27	−2.34, 3.50	.22	1.54	.73	0.31
Combo feedback group[a]	−2.64 ± 6.54	−6.26, 0.98	−2.96 ± 6.95	−6.81, 0.89				
Control group	−3.07 ± 9.62	−8.88, 2.74	−3.26 ± 8.27	−8.25, 1.74				
Hip flexion, °								
Self-feedback group	49.07 ± 10.31	43.36, 54.77	44.46 ± 9.41	39.25, 49.67	.02[b]	5.96	.09	2.60
Combo feedback group[a]	56.30 ± 14.19	48.44, 64.16	51.63 ± 9.89	46.16, 57.11				
Control group	53.98 ± 10.08	47.89, 60.07	52.50 ± 8.44	47.41, 57.60				
Hip abduction (−)/adduction (+), °								
Self-feedback group	−3.66 ± 3.87	−5.80, −1.52	−3.13 ± 6.16	−6.54, 0.28	.53	0.40	.41	0.90
Combo feedback group[a]	−3.77 ± 5.56	−6.84, −0.69	−3.74 ± 6.12	−7.13, −0.35				
Control group	−4.34 ± 5.84	−7.87, −0.81	−6.75 ± 5.07	−9.82, −3.69				
Peak knee flexion								
Knee flexion (−)/extension (+), °								
Self-feedback group	−66.31 ± 10.76	−72.27, −60.35	−70.42 ± 8.56	−75.15, −65.68	.14	2.29	.05	3.22
Combo feedback group[a]	−76.37 ± 11.06	−82.50, −70.25	−76.36 ± 14.64	−84.47, −68.26				
Control group	−67.96 ± 8.08	−72.84, −63.08	−70.50 ± 7.99	−75.32, −65.67				
Knee valgus (−)/varus (+), °								
Self-feedback group	−0.91 ± 9.74	−6.30, 4.48	−1.93 ± 11.33	−8.21, 4.34	.02[b]	5.65	.43	0.86
Combo feedback group[a]	−3.31 ± 7.54	−7.49, 0.86	−7.58 ± 13.11	−14.84, −0.32				
Control group	−3.26 ± 11.11	−9.97, 3.45	−8.49 ± 13.63	−16.73, −0.25				
Hip flexion, °								
Self-feedback group	63.10 ± 10.81	57.12, 69.08	61.71 ± 11.31	55.45, 67.97	.04[b]	4.38	.21	1.64
Combo feedback group[a]	65.80 ± 15.59	57.17, 74.43	71.81 ± 15.30	63.34, 80.28				
Control group	59.36 ± 9.72	53.48, 65.23	64.82 ± 10.04	58.75, 70.88				
Hip abduction (−)/adduction (+), °								
Self-feedback group	−3.08 ± 6.26	−6.55, 0.39	−3.78 ± 5.44	−6.80, −0.77	.18	1.88	.98	0.03
Combo feedback group[a]	−2.82 ± 4.70	−5.42, −0.22	−4.84 ± 5.58	−7.93, −1.75				
Control group	−3.72 ± 6.94	−7.92, 0.47	−3.89 ± 6.03	−7.53, −0.25				

Abbreviation: CI, confidence interval.

[a] The combination feedback group received self-feedback and expert video feedback.

[b] Indicates difference.

flexion was less for the pretest than for the retention test ($P = .03$, Cohen d = 0.29). Knee valgus at peak knee flexion was less at the posttest than at the retention test ($P = .02$, Cohen d = 0.36).

We noted a main effect of test time for hip flexion at peak knee flexion during the box–drop-jump task ($F_{2,80} = 6.04$, $P = .004$). Hip flexion was greater at the posttest than at the pretest ($P = .003$, Cohen d = 0.35). We also observed that hip flexion was greater at the retention test than the pretest ($P = .04$, Cohen d = 0.31). Furthermore, we found a main effect of test time for hip abduction at peak knee flexion ($F_{2,80} = 10.72$, $P < .001$). Hip abduction was greater at the pretest than at the posttest ($P < .001$, Cohen d = 0.42) and the retention test ($P < .001$, Cohen d = 0.47).

Running–Stop-Jump Task Over Time (Pretest to Posttest to Retention Test)

At initial contact, we demonstrated a main effect of test time for hip flexion during the running–stop-jump task ($F_{1,40} = 5.96$, $P = .02$). Hip flexion was greater at the posttest than at the retention test ($P = .02$, Cohen d = 0.31). In addition, a main effect of test time for knee valgus at peak knee flexion was found ($F_{1,40} = 5.65$, $P = .02$). Knee valgus at peak knee flexion was less at the posttest than at the retention test ($P = .02$, Cohen d = 0.27). Lastly, we found a main effect of test time for hip flexion at peak knee flexion ($F_{1,40} = 4.38$, $P = .04$). Hip flexion at peak knee flexion was greater at the retention test than at the posttest ($P = .04$, Cohen d = 0.25).

Sidestep-Cutting Maneuver Retention Test

We found no difference among feedback groups for any of the dependent variables during the sidestep-cutting maneuver task ($F_{2,40}$ range = 0.02–1.40, $P > .05$). Descriptive statistics, F statistics, and P values for the sidestep-cutting maneuver are reported in Table 3.

DISCUSSION

Our main finding was an improvement for feedback group during the box–drop-jump task. Peak knee flexion was greater for the combo feedback group than for the self-feedback group. We hypothesized that peak knee flexion during the box–drop-jump task would be greater for the combo feedback group than for the self-feedback and control groups. The results confirmed what we initially

Table 3. Descriptive Statistics for the Sidestep-Cutting Maneuver

Sidestep-Cutting Maneuver	Mean ± SD	95% Confidence Interval Lower	95% Confidence Interval Upper	$F_{2,40}$ Value	*P* Value
Initial contact					
Knee flexion (−)/extension (+), °	−18.99 ± 5.89	−20.81	−17.18	0.32	.73
Knee valgus (−)/varus (+), °	−6.1 ± 4.47	−7.48	−4.73	0.72	.49
Hip flexion, °	44.99 ± 7.34	42.73	47.25	0.35	.70
Hip abduction (−)/adduction (+), °	−6.67 ± 5.94	−8.49	−4.84	1.29	.29
Peak knee flexion					
Knee flexion (−)/extension (+), °	−47.14 ± 6.17	−49.04	−45.24	0.23	.80
Knee valgus (−)/varus (+), °	−5.27 ± 7.73	−7.65	−2.89	0.02	.98
Hip flexion, °	36.08 ± 8.44	33.48	38.68	1.40	.26
Hip abduction (−)/adduction (+), °	−8.15 ± 6.42	−10.13	−6.17	0.47	.63

hypothesized; the participants who received combo feedback had greater peak knee flexion than the self-feedback group. Oral and visual feedback also have been used to reduce landing forces.[28,37,38] Onate et al[37] used a simple jump-landing task in which participants were instructed to stand directly behind the force plates and jump as high as they could, touching a Vertec (Sport Imports, Columbus, OH) jumping instrument with their dominant hands. Peak vertical ground reaction forces were lower in the group that received both oral and self-video feedback than in the sensory and control groups.[37] Although we did not study the kinematics of the jump-landing task, we provided evidence about the effectiveness of using oral and video feedback and its ability to improve lower extremity kinetics.

Although peak knee flexion was the only variable that differed among feedback groups, this finding is relevant because of the important role knee flexion is thought to play in ACL injuries.[6–8] Researchers[15,57,58] have found that females display smaller knee-flexion angles than males during jump-landing activities. We showed that oral and combination video feedback after simple instruction also effectively improved peak knee-flexion angles during the box–drop-jump task, potentially placing the participant in a body-alignment position that can reduce her risk of ACL injury.

We noted an improvement across test time for the box–drop-jump task, which also supported our hypotheses. Participants had greater hip flexion at peak knee flexion during the posttest and retention test than during the pretest. In addition, the hip-flexion angle at peak knee flexion for the running–stop-jump task was greater during the retention test than the posttest. These results may suggest that learning occurred and was maintained across the 1-month timeframe. Researchers[59] studying sex differences have shown that females tend to land from a jump with a reduced hip-flexion angle. This is noteworthy because an athlete landing with a more erect posture, including a smaller hip-flexion angle and smaller knee-flexion angle, could be at greater risk for an ACL injury.[7] Given that participants could improve their hip flexion at peak knee flexion from pretest to posttest and from pretest to retention test, they seem to have learned and retained the feedback, leading to better lower extremity alignment and possibly a decreased risk of ACL injury.

Contrary to our hypotheses, none of the other lower extremity kinematic variables (knee valgus, hip flexion, and hip abduction) were different among feedback groups at initial contact or peak knee flexion during the box–drop-jump and running–stop-jump tasks. In a similar study, Onate et al[36] also did not find differences among feedback groups for knee flexion at initial contact during a running–stop-jump task. Although their feedback was given for a participant's landing after a running–stop-jump task and ours was given for the landing from a box-drop task, these similar forms of feedback did not appear to effectively provide information about initial contact. One reason that these variables, particularly knee flexion at initial contact, may not have been different among the groups could be the feedback provided. Whereas our feedback tool focused on both the knee and hip angles, it did not divide the movement into initial contact and peak knee-flexion timeframes. Instead, the feedback was based on more global movements of the joints. An example of this feedback includes questions about whether the knee angle was greater than 30° or the trunk was in front of the hips.

Finally, knee flexion at initial contact and hip flexion at initial contact decreased from posttest to retention test during the box–drop-jump task, indicating that a learning effect was not retained. A decrease in knee flexion at initial contact has been linked to an increased risk of ACL injury.[6,8] In one study, 91.7% of all noncontact ACL injuries occurred when the knee was flexed to less than 30° at initial contact.[6] Although knee flexion at initial contact did not decrease from pretest to posttest in our study, the decrease from posttest to retention test, regardless of feedback, was not ideal because the mean value at retention test was 19.43°, which is clearly less than the preferred knee-flexion angle at initial contact. This decrease in knee-flexion angle at initial contact from posttest to retention test in part may be due to the more global feedback given during the initial testing. Instead of distinguishing directly between how the participants should be landing at initial contact and at peak knee flexion, the feedback focused on joint positions for the overall jump landing.

We hypothesized that, at initial contact and peak knee flexion, the combo feedback group would have kinematic changes during the running–stop-jump task (initial transfer test) and sidestep-cutting maneuver (delayed transfer test) compared with the self-feedback and control groups. We found no difference among feedback groups for any of the kinematic variables at initial contact or peak knee flexion for either task. To our knowledge, authors of only 1 other study have provided instruction using similar feedback groups during a running–stop-jump task; however, Onate et al[36] used different methods than we did. The participants in their study performed a running–stop-jump task, simulating a jump ball in basketball. Participants then received feedback on their jump landing from this task. In our study, the feedback was given about the box–drop-jump landing and not the running–stop-jump task. Whereas no differences existed among feedback groups for the running–stop-jump task, we found a clinically important change that should not be dismissed. Mean peak knee flexion during the running–stop-jump task was greater for the combo feedback group than for both the self-feedback and control groups (Table 2). This result was similar to the difference in means of the box–drop-jump task (Table 1). Although the running stop was not different, it may have been influenced by instruction because the feedback was fresh in the participants' minds, whereas the sidestep-cutting maneuver was only performed 1 month after the feedback.

No other researchers have used the sidestep-cutting maneuver as a delayed transfer test for box–drop-jump instruction, and no other researchers have provided feedback related to the performance of a sidestep-cutting maneuver. Given the lack of differences among feedback groups, we concluded that improvement did not transfer from learning the landing mechanics of the box–drop-jump task to the performance of a sidestep-cutting maneuver. This lack of transfer could be due to several reasons. First, using the theory of identical elements, one could state that not enough similar elements existed between the tasks for positive transfer to occur.[34,35,60] Although the sidestep-cutting maneuver and the box–drop-jump task both involve a landing phase, the 2 tasks are not that similar. The box–drop-jump task is not a sport-specific task and involves few outside influences. On the other hand, the sidestep-cutting maneuver is more complex and is influenced by other factors, such as the speed of approach, an anticipatory or unanticipatory maneuver, and the direction of cut. The box–drop-jump and running–stop-jump tasks also involve a deceleration followed by a stop in movement, whereas the sidestep-cutting maneuver is a deceleration followed by an acceleration with no actual stop in movement. Second, the sidestep-cutting maneuver was performed during the retention test portion of the study as a delayed transfer test, whereas the running–stop-jump task was performed during the immediate posttest as the initial transfer test.

CLINICAL IMPLICATIONS AND IMPORTANCE

Our results support the use of oral and visual feedback for a simple box–drop-jump task as a means to improve jump-landing lower extremity kinematics. In particular, the combination of self- and expert video feedback after a box–drop-jump task can improve peak knee-flexion angles during this task. Simple oral and video feedback appears to be an easy and effective tool that could be used in various clinical settings to improve lower extremity kinematics, particularly peak knee flexion. After a box–drop-jump task, quick and concise feedback can be given about lower extremity alignment using simple video equipment and the LESS criteria as a systematic feedback tool.

Having an athlete perform a box–drop-jump task may effectively simulate a jump in the clinical setting for evaluation or rehabilitation, but it is not specific to all tasks. This may be due to the complex, sport-specific nature of a task that differs greatly from the simple box–drop-jump task. Many factors are involved in such a sport-specific task, including mechanics, timing, defensive opponent, speed, strength, and all external and internal stimuli. Therefore, receiving feedback after a box–drop-jump task may be more beneficial for basketball athletes, who frequently perform a running–stop-jump task, than for soccer athletes, who tend to perform sidestep-cutting maneuvers more often.

Our findings and those of other researchers indicate that an appropriate clinical recommendation would be to implement video and oral feedback for a box–drop-jump task in an injury-prevention program or in an existing strength and conditioning program. This could be achieved by screening athletes using the LESS to find individuals who are at greater risk of injury. Feedback then could focus on this select group of athletes. A second method of implementation would be to provide video and oral feedback to all individuals on a team. Although some of these athletes may not be at risk, they still may improve a few degrees in some of their landing mechanics. This small improvement may not be statistically different, but any improvement in landing mechanics, whether small or large, is still an improvement.

CONCLUSIONS

We found that the use of oral and video feedback successfully improved lower extremity biomechanics during jump-landing activities. Specifically, the combination of self- and expert video feedback with oral feedback after a box–drop-jump task improved peak knee-flexion angles. Overall, the combination of self- and expert feedback is an easy, effective tool in changing lower extremity kinematics.

The use of simple oral and video feedback appears to be an easy and effective tool that could be used in almost all clinical settings to improve lower extremity kinematics, particularly peak knee flexion. Whereas teaching proper peak flexion angles is important, future research is needed to emphasize initial-contact landing mechanics in video and oral feedback. To improve more sport-specific task biomechanics, such as the running–stop-jump task and sidestep-cutting maneuver, box–drop-jump task feedback may not be as appropriate. Therefore, researchers also should focus on developing a feedback tool that relates specifically to the biomechanics of more sport-specific tasks, such as a sidestep-cutting maneuver or pivoting movement.

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