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Instruction of Jump-Landing Technique Using Videotape Feedback
Altering Lower Extremity Motion Patterns

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Background: Anterior cruciate ligament injury prevention programs have used videotapes of jump-landing technique as a key instructional component to improve landing performance.

Hypothesis: All videotape feedback model groups will increase knee flexion angles at initial contact and overall knee flexion motion and decrease peak vertical ground reaction forces and peak proximal anterior tibial shear forces to a greater extent than will a nonfeedback group. The secondary hypothesis is that the videotape feedback using the combination of the expert and self models will create the greatest change in each variable.

Study Design: Controlled laboratory study.

Methods: Knee kinematics and kinetics of college-aged recreational athletes randomly placed in 3 different videotape feedback model groups (expert only, self only, combination of expert and self) and a nonfeedback group were collected while participants performed a basketball jump-landing task on 3 testing occasions.

Results: All feedback groups significantly increased knee angular displacement flexion angles \( F(6,70) = 8.03, P = .001 \) and decreased peak vertical ground reaction forces \( F(6,78) = 2.68, P = .021 \) during performance and retention tests. The self and combination groups significantly increased knee angular displacement flexion angles more than the control group did; the expert model group did not change significantly more than the control group did. All feedback groups and the nonfeedback group significantly reduced peak vertical forces across performance and retention tests. There were no statistically significant changes in knee flexion angle at initial ground contact \( (P = .111) \) and peak proximal anterior tibial shear forces \( (P = .509) \) for both testing sessions for each group.

Conclusion: The use of self or combination videotape feedback is most useful for increasing knee angular displacement flexion angles and reducing peak vertical forces during landing.

Clinical Relevance: The use of self or combination modeling is more effective than is expert-only modeling for the implementation of instructional programs aimed at reducing the risk of jump-landing anterior cruciate ligament injuries.

Keywords: knee kinematics; ground reaction forces; anterior cruciate ligament (ACL); injury prevention

Lower extremity musculoskeletal injuries have become a public health concern for active individuals when considering the complications that often present later in life after injury (eg, degenerative joint disease). A recent surge of lower extremity injury prevention programs, specifically aimed at ACL injury prevention, have provided some promising results in reducing knee injury among young female athletes after a jump-landing instructional program. Investigators have generally attempted to influence different intrinsic factors (eg, balance, flexibility, and strength) to potentially reduce the incidence of lower extremity injury. An important aspect of any training program is the influence that instructional technique can provide in “educating” athletes to land properly and possibly reduce acute and chronic lower extremity injuries. Numerous investigators have evaluated the effects of information feedback on performance and learning of
motor skills. The process of providing extrinsic information to individuals concerning their movement kinematics is regarded as knowledge of performance, a process of augmented feedback that is defined as providing supplemental information to an individual above and beyond the inherent information that is naturally available to the individual. The use of an instructor using videotape augmented feedback within the realm of athletics is commonplace in a variety of sport settings (eg, golf or tennis swing instruction), yet its use in the sports medicine realm has been largely ignored. Recent research investigations have found success using augmented feedback to reduce impact loads during jump-landing tasks. A preliminary project on the effects of augmented feedback on jump-landing forces found that a combination of verbal cues and videotape feedback reduced peak jump-landing forces during an immediate same-day performance test, but more important, it significantly decreased jump-landing impact forces during a delayed retention test (1 week) by approximately 0.80 multiple of body weight reduction.

Current information is inconclusive as to the exact factors that predispose athletes to greater lower extremity injury risk, yet preliminary information leads us to believe that biomechanical landing patterns are associated with increased knee injury risk. Several investigators have speculated that ACL injuries frequently occur by approximately 0.80 multiple of body weight reduction.27 It is speculated that augmented feedback within the realm of athletics is commonplace in a variety of sport settings (eg, golf or tennis swing instruction), yet its use in the sports medicine realm has been largely ignored. Recent research investigations have found success using augmented feedback to reduce impact loads during jump-landing tasks.25,27,29 A preliminary project on the effects of augmented feedback on jump-landing forces found that a combination of verbal cues and videotape feedback reduced peak jump-landing forces during an immediate same-day performance test, but more important, it significantly decreased jump-landing impact forces during a delayed retention test (1 week) by approximately 0.80 multiple of body weight reduction.27

Current information is inconclusive as to the exact factors that predispose athletes to greater lower extremity injury risk, yet preliminary information leads us to believe that biomechanical landing patterns are associated with increased knee injury risk. Several investigators have speculated that ACL injuries frequently occur by approximately 0.80 multiple of body weight reduction.27 Kirkendall and Garrett18 hypothesized that women tend to land in a more erect position with less knee flexion, thus creating greater knee extensor loads and perhaps leading to a gender bias for females’ increased risk for ACL injury. Another study investigating knee joint motion patterns between men and women performing running, side-pivoting, and cross-pivoting activities revealed that female subjects tended to land in significantly lower amounts of knee flexion angles (difference of 8°) as compared to their male counterparts.21

The concept that augmented feedback can alter peak vertical ground reaction forces suggests that teaching proper landing mechanics may also have a positive influence on jump-landing kinematics, specifically increasing knee flexion angles. Recent ACL injury prevention programs13,20 have used videotapes of an expert model for jump-landing instruction as a key component in the intervention programs to instruct individuals on the proper jump-landing techniques to reduce potentially injurious forces. The concept of an “expert model” using proper technique when landing from a jump, in addition to verbal information regarding proper technique, is thought to positively influence an individual’s motor learning capabilities. The purpose of this study was to examine the effects of different model types (expert model, self model, and combination of expert and self [combo] models) of videotape augmented feedback on peak vertical ground reaction forces, peak proximal anterior tibial shear force, and knee flexion angles in collegiate-aged subjects. The primary hypothesis is that all videotape augmented feedback groups will decrease peak vertical ground reaction forces, reduction in peak proximal anterior tibial shear forces, and increase in knee flexion angles at initial foot contact, maximum knee flexion angle, and overall knee flexion motion to a greater extent than will a control group. The secondary hypothesis is that the combo model feedback will create the greatest reduction in peak vertical ground reaction forces, reduction in peak proximal anterior tibial shear forces, and increase in knee flexion angles at initial foot contact, maximum knee flexion angle, and overall knee flexion motion as compared to all groups.

METHODS

Subjects

Fifty-one healthy recreational athletes (defined as exercising a minimum of 3 times per week for a minimum of 20 minutes) between the ages of 18 and 25 were recruited from recreational sports and exercise science courses to volunteer to participate in the study. Kinetic analysis was completed on all 51 recruited subjects, with a smaller subsample of 40 subjects undergoing 3-dimensional (3-D) kinematic and kinetic analyses owing to the number of acceptable captured kinematic trial sessions. Subjects were excluded if they had sustained a previous lower extremity injury within the past 2 months that limited activity for more than 1 day, had a current self-reported history of lower extremity instability, underwent any previous lower extremity surgery within the past 2 years, or had any formal training in jump landing before participation in the current study. All subjects signed an informed consent statement that was approved by the University of North Carolina at Chapel Hill Medical School’s Institutional Review Board.

Design

A randomized controlled design consisting of 4 experimental groups and 2 testing sessions was used. Subjects were randomly placed into a videotaped expert model augmented feedback group (expert), a videotaped self model augmented feedback group (self), a videotaped combo model augmented feedback group, or a nonfeedback group (control) based on the order of recruitment. Subjects were randomized to groups by being assigned to a group based on the order in which they signed up for the initial baseline testing session. Subjects were placed into a group in the following order: expert, self, combo, and control. Once the first 4 subject test sessions were complete, then the order of group placement was repeated for the next subjects who volunteered for the study. The expert group viewed an expert model trained in proper landing technique by the principal investigator. The biomechanical characteristics of an expert model jump landing were theorized from the previous work of various investigators.3 The checklist for landing given to the subjects was the technique used by the “expert model” during landing, which consisted of the following criteria: (1) landing with both feet at the same time, (2) landing in a neutral knee valgus/varus position, (3)
landing with feet shoulder-width apart, (4) landing on forefoot and rolling toward rearfoot, and (5) landing with optimal knee and hip flexion at initial contact to be greater than 20° and estimated to be a total of approximately 90°, respectively. The self group viewed their own videotaped jump-landing trials. The subjects in the combo group first watched the initial 2 trials performed by the expert model in each view, and then they watched their first 3 initial jump-landing trials with the same protocol used for the expert model review. The control group did not receive any feedback concerning any of their jumps across test trials and during their rest period were instructed to work on a computer with restrictions to not investigate jump-landing programs.

Subjects were assessed during 3 testing sessions: baseline, performance, and retention testing using a Jump-Ball (patent pending) testing device. The performance test immediately followed 3 sets of training feedback, and the retention test was conducted 1 week later. At performance and retention tests, all subjects in each of the 4 groups were instructed to land as softly as possible. No such jump-landing instruction was provided during the baseline test.

Procedures

Subjects wore the same athletic attire, consisting of spandex shorts, sports bra (females) or no shirt (males), and athletic shoes, during all testing sessions. Subjects were measured for height, weight, and standing arm reach using a Jump-Ball testing instrument (Figure 1). The Jump-Ball instrument is a modified Vertec (Sports Imports Inc, Columbus, Ohio) jump-instrument design with a ball attachment device that allows subjects to jump and grab a basketball attached to the end of a line set at a predetermined height. After the collection of demographic information, subjects were instructed to perform a brief warm-up session consisting of light jogging and stretching. After practice trials of the jump-landing task, 13 reflective markers 2 cm in diameter were affixed with double-sided tape to the subject (Figure 2). A standing marker placement evaluation was conducted with the subjects standing in the anatomical position with their feet shoulder-width apart. The foot placement was recorded by having the subjects stand on poster-board paper while the investigator drew an outline of their foot position to allow for stance replication during the follow-up testing session. A permanent pen marker was used to draw a circle in the area of the marker placements to allow for duplication of marker placement in case one became dislodged during testing. Subjects were given a permanent pen marker to take home and were asked to fill in the marker placement areas each day before their follow-up testing. During the follow-up testing session conducted 1 week later, all attempts were made to replicate the reflective marker placement of the initial day of testing by matching marker placement to circled area.

Maximum Vertical Jump Test

After the brief warm-up, subjects were given 3 practice jumps to get accustomed to the landing surface and the Jump-Ball testing instrument. Subjects were positioned 4 m behind 2 Bertec (Bertec Corp, Columbus, Ohio) analog force plates that provided a combined landing surface of 60 cm long and 80 cm wide. The Jump-Ball device was placed 21 cm on the left side of the subject, allowing for a piece of cardboard to be directly over the landing zone. All subjects began a running approach 4 m away from the force plate and were instructed to start the takeoff of their jumps with the left foot contacting a tape line placed at an anterior distance, calculated as 30% of maximal standing arm reach. Subjects proceeded to perform a single-leg takeoff onto the force plates, land with 2 feet, jump into the air to simulate grabbing a basketball, contact a piece of card-
board extended on the Jump-Ball device, and then return to land onto the force plate with 2 feet. Subjects had washable finger paint applied to each hand and were asked to raise both arms directly overhead as high as possible and grasp a piece of cardboard attached to the Jump-Ball device, while keeping their torsos erect and their feet flat on the ground. Three maximal vertical jump tests were performed with the subjects instructed to jump as high as they could by hitting the cardboard with both of their hands and landing onto the force plate landing zone, with one foot landing on each force plate. The cardboard was used to allow for an accurate evaluation of maximum jump height based on arm reach and the apparatus used to suspend the ball, rather than conducting numerous trials to see at what height the basketball could be grabbed successfully. A timing system recorded the amount of time from starting position to the takeoff line for each practice trial. The mean speed of the 3 maximum jumping trials was calculated, and the subjects were instructed during each testing trial whether they successfully maintained ±10% of the mean approach speed time. After 3 maximal vertical jump attempts, subjects were given 2 minutes of rest.

Jump Testing Trials

All testing trials were conducted in a similar fashion to the maximum jumping trials, with the Jump-Ball device adjusted to include a regulation-size basketball set to 80% of the subject’s maximal vertical jump height based on the best attempt obtained during the preliminary maximal vertical jump height test. After the calculation of the mean approach speed taken during the maximal jump test, subjects were familiarized with the basketball-rebounding task using 3 practice trials. After the initial practice set, subjects completed 5 separate individual jumping trials with a rest time of 30 seconds between each jump. The goal for all subjects in each testing group (3 feedback and 1 control) for baseline testing was to “land in their normal manner.”

After the completion of the baseline jumps, subjects in the videotape augmented feedback groups received instruction, whereas subjects in the control group were allowed the same amount of time to rest as the feedback groups but were not given any instructional feedback as they worked on a computer. After the completion of the feedback or rest session, all subjects in each testing group (3 feedback and 1 control) were instructed to perform 5 more jumping trials with the goal of “landing as soft as possible” using the information that they received during the feedback session. The set of 5 jumping trials and then feedback or rest occurred 3 times during the skill acquisition phase. After the third set of feedback or rest, the subject’s 5 trials were assessed and scored as the immediate performance test. Each jump-landing trial after the initial feedback/rest session contained instructions to “land as softly as possible.” During each jumping session, all subjects were instructed to run at full speed, perform a stop-jump onto the force plates, and reach to grab a ball with both hands, resembling a basketball rebound. The goal of the task was to jump and grab the ball and land back onto the force plates with one foot on each force plate. Videographic data were collected for all subjects to allow for visual analysis of each jump trial and to replicate the testing environment for each testing group.

Two S-VHS video camcorders (30-Hz frame rate) used for videotape information were placed in frontal and sagittal plane views of the landing zone. The first (baseline test) and fourth (performance test) sessions were analyzed, and the second and third sessions used as the skill acquisition practice sessions were not analyzed for this study.

After the initial day of testing, subjects were asked to return approximately 1 week later (7 ± 1 days) for a reten tion test consisting of 5 jumps after 3 practice trials, with the goal of “landing as soft as possible” reiterated before their testing trials. Each subject was given instructions to not discuss the augmented feedback information with other subjects, to not investigate any other jump-landing-related programs, and to not perform any physical practice of their jump-landing technique during the interim week. Subjects were allowed to continue normal activities during the week but were asked to limit exercise participation 24 hours before testing sessions.

Videotape Feedback

Subjects viewed a video monitor for each jumping trial; 5 trials were viewed during each feedback session with each trial being viewed 2 times (first at regular speed and second in slow motion as controlled by the investigator). Subjects watched all the frontal view trials initially and then the sagittal view for each jumping trial. Subjects analyzed each jumping trial using a checklist to ensure that specific criteria were evaluated that have been theorized to decrease jump-landing forces. The jump-landing technique instructional checklist consisted of yes-no answers to questions regarding the following: (1) Did model land on both feet at the same time? (2) Did model land with excessive knee valgus or varus? (3) Did model land with feet shoulder-width apart? (4) Did model land on forefoot and roll toward rearfoot? (5) Did model land with optimal knee and hip flexion? Optimal knee flexion and hip flexion were determined by visual assessment of the videotape trials by the experienced principal investigator to reflect knee and hip flexion at initial contact to be greater than 20° and estimated to be a total of approximately 90°, respectively. The same instructor provided oral feedback for each subject by evaluating the checklist criteria with the subject for each jump and explaining whether optimal technique was viewed. Each feedback group was given the same amount of time and number of trials for feedback; the difference was which type of model they viewed performing jump-landings. The combo model group viewed 2 trials of the expert model and 3 trials of their own jumps to maintain an equal amount of feedback time and number of trials for feedback.

Data Collection

Kinetic data collection was conducted by using 2 (40 × 60-cm) 4060 series Bertec force plates (Bertec Corp) built into the flooring and placed together for a landing zone of 80
cm wide and 60 cm long. All ground reaction forces and moments were collected using 2 Bertec analog-to-digital converter units set at gains of 5, and they were then sent to a DATAPAC 2000 motion analysis system (Datapac, Dublin, Ireland). The analog data were collected at a rate of 1000 Hz to allow for proper sampling of the rapid jump-landing sequence. The force plate was triggered manually by the investigator after instructions were given to the subjects that it was okay to jump, at which time the subjects proceeded at their own discretion to run, stop-jump, grab the basketball set at 80% maximal vertical jump height, and land with both feet on the force plate. The raw analog force plate data were exported into an ASCII formatted spreadsheet and transferred to an MS3D 5.0 MotionSoft force plate motion analysis software system (MotionSoft, Chapel Hill, NC) for reduction into ground reaction force data. The peak vertical ground reaction force data (defined as the maximum value during the landing phase of the jump) for each trial were then normalized to the subject’s body weight and expressed in both kilograms and multiples of body weight for statistical and clinical analysis.

The Peak Performance Motus 6.01 real-time motion analysis system (Peak Performance Technologies Inc, Centennial, Colo) was used for 3-D coordinate reduction. Six cameras operating at 120 frames per second were used with a calibrated volume space of 1.5 m long × 2 m wide × 2 m high above the ground site. The camera angles allowed all reflective markers to be seen by at least 2 cameras throughout each maneuver. The 2-D trajectories of all critical reflective markers were automatically tracked using the Peak Performance Motus 6.01 software and corrected with manual digitization as needed. The 3-D coordinates of the reflective markers were filtered through a low-pass Butterworth digital filter at estimated optimum cutoff frequencies. An embedded right-hand Cartesian coordinate system was defined for each lower extremity segment to describe the position and orientation of the segment. The longitudinal axis of the thigh was defined as the line between the critical reflective markers at the greater trochanter and lateral femoral condyle. The longitudinal axis of the tibia was defined as the line between the critical reflective markers at the lateral femoral condyle and the lateral malleolus. The unit vector formulations using the reflective marker coordinates for knee joint angle calculations are similar to those described by Kadaba et al. With these embedded coordinate systems, the knee joint angles were determined using the floating-axis or Euler angle convention described by Chao. The knee flexion angle at initial ground contact was defined as the knee flexion value obtained during the initial ground contact of the foot onto the force plate measured by the vertical ground reaction force data. The peak vertical ground reaction force (defined as the maximum value during the landing phase of the jump) for each trial was then normalized to the subject’s body weight and expressed in both kilograms and multiples of body weight for statistical and clinical analysis.

The mean of all the “acceptable” trials for each testing session was evaluated with a minimum of 2 and a maximum of 5 trials per testing session. An acceptable trial was defined based on the following criteria for each subject: hands did not touch the ground, both feet landed fully on each respective force plate, speed approach was within ±10% of maximal effort approach mean, basketball was successfully grabbed and pulled to chest, and each marker point was in view for kinematic digitization.

Data Analysis

The mean of all the “acceptable” trials for each testing session was evaluated with a minimum of 2 and a maximum of 5 trials per testing session. An acceptable trial was defined based on the following criteria for each subject: hands did not touch the ground, both feet landed fully on each respective force plate, speed approach was within ±10% of maximal effort approach mean, basketball was successfully grabbed and pulled to chest, and each marker point was in view for kinematic digitization. The critical point for an unacceptable trial was the digitization process that occurred after testing during data reduction; thus, we allowed a maximum of 8 trials to be conducted. All subjects completed a mandated 5 trials, and an additional maximum of 3 trials per session were completed if any errors occurred. An additional jump was conducted only if a subject failed to complete a landing trial successfully or the investigator thought that the markers were obscured during the digitizing process. The mean number of trials for all subjects for each session was 4.57 (SD, ±0.97) and was not considered to be substantially different for each subject; thus, it was concluded that each subject’s practice time for the jump-landing task was similar.

A mixed-model, repeated-measures analysis of covariance (ANCOVA) with 1 between-subjects (group) and 1 within-subjects (test) factor was performed between feedback groups after 3 test sessions of a jump-landing task. Jump-Ball height and body weight were used as the covariates for each analysis. Individuals with greater jumping ability may land in different positions based on height of jump rather than individual preference. We chose not to block this variable because of the various jumping capabilities of each subject, and we did not wish to choose a task that resulted in exact jump height replication for each subject (eg, box-drop) because we were attempting to replicate a sport-specific movement task. A separate ANCOVA was performed on 2 kinetic dependent variables, peak vertical ground reaction force and peak proximal anterior tibial shear force, and 2 kinematic dependent variables, knee flexion angle at initial ground contact and knee angular displacement flexion angles. The assumption of parallelism of the ANCOVA conducted on the peak vertical ground reaction forces was relaxed by including the group by covariate terms in the statistical model because the departure of parallelism was of a linear departure. A separate ANCOVA was also performed on the change
scores from baseline for performance and retention tests on the peak vertical ground reaction force data. In addition, a significant test × group × weight × gender interaction was found, but adjusting for gender did not change the effects for the other variables; therefore, in the interests of parsimony, gender was excluded from the models presented in this investigation. Peak vertical ground reaction force analysis was performed on the kilograms of force owing to the ANCOVA assumption of using measures that are on a continuous scale. The ANCOVA assumptions of homogeneity of variance, linearity, and parallelism criteria were evaluated and validated for the use of ANCOVA analyses. The feedback group was the between-subjects factor, and the testing session was the within-subjects factor. The alpha level was set a priori at the .05 level. Tukey post hoc analyses were performed to assess specific differences between the 4 feedback groups and 3 testing sessions. An additional analysis of the post hoc scores was conducted by using a degree-of-difference ratio evaluated as the difference between scores divided by the Tukey post hoc critical value. A follow-up analysis to this measure was a repeated-measures ANCOVA on peak vertical ground reaction forces expressed as a multiple of body weight change scores.

RESULTS

Sample Characteristics

Sample characteristics of age, height, weight, jump height, and approach speed are presented in Table 1. The means, SDs, and $P$ values of the within- and between-subjects effects for peak vertical ground reaction force, peak proximal anterior tibial shear force, knee flexion angle at initial contact, maximum knee flexion angle, and knee angular displacement flexion angle for each group are presented in Table 2.

Marker Placement Reproducibility

The intrasubject reproducibility of marker location for kinematics during the jump-landing task was evaluated using a single-measure intraclass correlation coefficient (ICC 2,1). An ICC was performed for the smoothed coordinate data for the knee for the $x$, $y$, and $z$ components based on 1 initial pretesting stance trial for each testing session. The ICC values for each of the 3 coordinate data points between test days (ICC = 0.6681, 0.9650, and 0.9909; SEM = 0.014, 0.004, and 0.006 for $x$, $y$, and $z$, respectively) were deemed to be moderate to excellent for marker placement reproducibility at the knee. Overall, the reproducibility of the marker placement between testing days was deemed acceptable to excellent.

Peak Vertical Ground Reaction Force

Statistical analysis revealed a significant test by group interaction, $F(6,78) = 2.68, P = .021$ (Figure 3), showing that peak vertical ground reaction forces for performance and retention tests were significantly reduced as compared to baseline scores. Tukey post hoc analyses revealed that each feedback group significantly reduced their peak vertical ground reaction forces in both performance and retention tests as compared to baseline scores. An additional analysis of the post hoc scores was conducted by using a degree-of-difference ratio evaluated as the difference between scores divided by the Tukey post hoc critical value. A follow-up analysis to the degree-of-difference ratio was conducted using a repeated-measures ANCOVA on peak vertical ground reaction forces expressed as a multiple of body weight change scores with jump height as the covariate. The performance test post hoc analyses indicated that the combo feedback group (1.36 multiple of body weight reduction; degree of $D$ ratio = 2.17) significantly reduced their peak vertical ground reaction force to a greater extent than did the expert feedback group (0.93 multiple of body weight reduction; degree of $D$ ratio = 1.63) (Figure 4). The retention test post hoc analyses indicated that both the self feedback group (1.58 multiple of body weight reduction; degree of $D$ ratio = 2.71) and combo feedback group (1.48 multiple of body weight reduction; degree of $D$ ratio = 2.32) significantly reduced their peak vertical ground reaction forces to a greater extent than did both the expert feedback group (1.03 multiple of body weight reduction; degree of $D$ ratio = 1.76) and the control group.
## TABLE 2

Kinetic and Kinematic Group by Session Scores \(^a\)

<table>
<thead>
<tr>
<th></th>
<th>Expert Model</th>
<th>Self Model</th>
<th>Combination Model</th>
<th>Control Group</th>
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<td></td>
<td>Baseline</td>
<td>Performance</td>
<td>Retention</td>
<td>Baseline</td>
<td>Performance</td>
</tr>
<tr>
<td>Peak vertical ground reaction force, mBW</td>
<td>4.27 (1.41)</td>
<td>3.34 (0.65)</td>
<td>3.24 (0.66)</td>
<td>4.56 (1.13)</td>
<td>3.33 (0.51)</td>
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<tr>
<td>Peak proximal anterior tibial shear force, mBW</td>
<td>0.79 (0.20)</td>
<td>0.72 (0.18)</td>
<td>0.79 (0.21)</td>
<td>0.80 (0.12)</td>
<td>0.64 (0.09)</td>
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<td>Knee flexion angle at initial contact, degrees</td>
<td>18.32 (3.66)</td>
<td>23.24 (4.14)</td>
<td>24.17 (3.89)</td>
<td>21.51 (3.55)</td>
<td>27.27 (5.61)</td>
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<tr>
<td>Maximum knee flexion angle, degrees</td>
<td>57.28 (8.03)</td>
<td>84.73 (7.71)</td>
<td>83.86 (10.29)</td>
<td>54.76 (3.71)</td>
<td>90.02 (7.40)</td>
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<tr>
<td>Knee flexion angular displacement, degrees</td>
<td>38.96 (12.40)</td>
<td>61.49 (11.29)</td>
<td>59.69 (16.69)</td>
<td>33.25 (3.87)</td>
<td>62.75 (9.19)</td>
</tr>
</tbody>
</table>

\(^a\)Data are presented as mean (\(\pm\)SD). mBW, multiple of body weight. Knee flexion angles are in angular degrees.

\(^b\)\(P < .05.\)

\(^c\)Knee flexion angular displacement angle calculation: knee flexion angle maximum minus knee flexion angle at initial contact.
There were no significant differences in the amount of peak vertical ground reaction force reduction between self and combo feedback groups and between expert feedback and control groups, respectively, for the retention test.

Peak Proximal Anterior Tibial Shear Force

Statistical analysis revealed that there was no significant main effect for test session, $F_{(2,56)} = 0.27, P = .763$, or a significant test by group interaction, $F_{(6,56)} = 0.80, P = .573$ (Table 2), thus indicating that peak proximal anterior tibial shear forces for performance and retention tests were not significantly reduced as compared to baseline scores across all groups.

Knee Flexion Angles at Initial Ground Contact

Statistical analysis revealed that there were no significant between-subjects effects, $F_{(3,35)} = 2.15, P = .111$; within-subjects main effect for test session, $F_{(2,76)} = 0.66, P = .520$; or a significant test by group interaction, $F_{(6,70)} = 1.71, P = .131$, for knee flexion angle at initial ground contact for performance and retention tests as compared to baseline scores (Table 2), yet a trend ($P = .111$) was noted that revealed a 5° to 6° increase in knee flexion angle at initial ground contact as compared to baseline scores for the combo and self feedback groups versus the expert and non-feedback control groups across both testing sessions (Table 2).

Maximum Knee Flexion Angle

Statistical analysis revealed that there was a significant test by group interaction, $F_{(6,70)} = 7.29, P = .001$, and between-subjects effects, $F_{(3,35)} = 3.018, P = .044$, for knee flexion maximum angle for performance and retention tests as compared to baseline scores (Figure 5). Tukey post hoc analyses revealed that each videotape testing group and the nonfeedback control group significantly increased their knee flexion maximum angles in both performance and retention tests as compared to baseline scores. In addition, it was found that the self and combo videotape feedback groups had significantly greater knee flexion maximum angles as compared to the control group at both the performance and retention test sessions.

Knee Angular Displacement Flexion Angle

Statistical analysis revealed that there was a significant test by group interaction, $F_{(6,70)} = 8.03, P = .001$, for knee angular displacement flexion angles for performance and retention tests as compared to baseline scores (Figure 6). Tukey post hoc analyses revealed that each videotape augmented feedback group significantly increased their knee angular displacement flexion angles in both performance and retention tests as compared to baseline scores but that the control group did not significantly change as compared to baseline. A Tukey post hoc analysis also revealed that the combo group significantly increased their knee angular displacement flexion angle to a greater extent as com-
The main finding of our investigation was that subjects trained with videotape augmented feedback significantly decreased peak vertical ground reaction forces and increased maximum knee flexion angles and knee angular displacement flexion angles in both immediate performance testing (same day) and delayed retention testing (1 week) across all groups. Subjects trained with the self videotape augmented feedback model or a combination of self and expert videotape augmented feedback models had significantly more decreases in peak vertical ground reaction forces and increases in maximum knee flexion angles and in knee angular displacement flexion angles than did the control group in a 1-week retention test. The results of our investigation support the main hypothesis that videotape augmented feedback appears to provide relevant information for decreasing peak vertical ground reaction forces, increasing maximum knee flexion angles, and increasing knee angular displacement flexion angles across immediate performance and delayed retention tests.

The results of this study also support the secondary hypothesis that a combination of the self and expert videotape models provides greater decrease of peak vertical ground reaction force, increase of maximum knee flexion angle, and increase of knee angular displacement flexion angle as compared to videotape augmented feedback using an expert model or a nonfeedback control group. In addition, we found that the self videotape augmented feedback group increased their knee angular displacement flexion angles to a greater extent than did the control group and the expert group. The expert group did not differ significantly from the control group in terms of range of knee flexion. These results appear to suggest that videotape augmented feedback is more effective as a training tool if it includes review of one’s own landing technique in addition to, or instead of, review of an expert model to increase jump-landing knee angular displacement flexion angles. This finding supports the need for individualized videotape augmented feedback using a self model to enhance jump-landing instruction.

The concept of using a self model of visual demonstration to optimally increase knee flexion range of motion (defined as reaching maximum knee flexion of 90° from initial foot contact) during jump-landing instruction substantiates recent investigations indicating that the use of a learning model (ie, self) is best for motor learning. The ability for individuals to view themselves performing correctly or making mistakes and responding to the corrections is of greater value to individuals than is viewing an expert model performing the task correctly. One theoretical approach is that learning is a problem-solving process; the more involved the individual is in analyzing his or her own performance, the greater the learning value. An alternative theoretical notion stated that the more correct the visual demonstration, then the more accurate the cognitive representation that will be formed, resulting in increased learning. Our findings support the learning model of visual demonstration and the need for athletes to become actively involved in the visual demonstration by evaluating the mistakes and corrections of their trials.

Several investigators have speculated that ACL injuries frequently occur with the knee at small flexion angles during the jump-landing motion. One of the main roles of the ACL is to prevent the proximal anterior tibia from excessively translating anteriorly on the distal femur. The hamstring musculature provides additional support to the ACL in resisting anterior tibial translation, yet adequate knee flexion requirements are needed to provide the hamstring musculature the proper line of pull to perform this function. It has been theorized by McNair and Marshall, investigating the correlation of vertical...
ground reaction force and anterior tibial translation, that reduction of impact force may be beneficial in reducing the amount of stress applied to the knee joint, yet knee kinetic data have not yet proven this theory conclusively. A follow-up to this study should investigate the effects of knee flexion angle on estimated peak anterior tibial shear forces at the knee. It should be noted that the intervention aspects of this study did not significantly reduce peak anterior tibial shear forces. In addition, we were unable to find any other ACL intervention studies that successfully reduced peak proximal anterior tibial shear forces, which may be a critical component in reducing ACL injuries. Future ACL intervention studies should focus on the aspects of reducing peak proximal anterior tibial shear force and evaluating its effect on ACL injury. A secondary result of this study was that the videotape feedback was successful in reducing peak vertical ground forces in each testing group across both test sessions. The findings of this study do support the idea that a self or combination of self-expert videotape feedback models significantly increases knee angular displacement flexion angles during both immediate performance and delayed retention testing better than an expert or control model. This finding is important following the current trend in videotape instruction for patients who have suffered chronic lower extremity injuries resulting from repetitive jump-landing tasks due to sport requirements (eg, volleyball, basketball, and gymnastics) or in the incorporation of jump-landing instructional techniques for the prevention of injury (eg, ACL injury prevention programs). The current concept is to provide individuals with techniques to improve (ie, land with greater knee flexion motion) landing performance and provide learners with an expert demonstration of the correct technique. Future ACL intervention programs may need to provide individualized videotape instructional review of jump-landing technique to allow individuals to view how they personally perform the movement task and actively problem solve to develop techniques to obtain proper jump-landing form.

Previous investigations have shown success at decreasing landing forces using various methods of augmented feedback (eg, verbal cues or verbal instruction), but this study is one of the first investigations to find beneficial effects of videotape feedback on reducing peak vertical ground reaction force and improving knee kinematic jump-landing technique. McNair et al. found that the use of instructions related to kinematics can minimize impact forces when landing from a drop-jump, which they theorized occurred as a result of instruction stressed on increasing knee flexion angle during landing. Our findings are in agreement with this theory as all videotape augmented feedback groups were able to significantly decrease their peak vertical ground reaction forces across both performance and retention testing sessions.

One limitation to the study design was the aspect of the different landing goals from pretesting to posttesting sessions. All groups received information to land normally during the baseline test and then to land “as softly as possible” during the postbaseline testing trials. This information was given purposefully to evaluate the effects of instructional goal on the task and to evaluate whether a goal of “soft landing” was sufficient to decrease peak vertical ground reaction forces. It is interesting to note that all groups had significant reductions across testing days, showing that the goal of the task may have influenced individuals’ landing forces, but the combo and self model feedback groups were significantly better at reducing landing forces as compared to the control groups. This result indicates that jump-landing instruction possibly enhances the ability of a person to land “softer.” In addition, all videotape augmented feedback groups were able to increase their knee angular displacement flexion angles immediately on the same day of instruction and retain it across a 1-week retention test. An interesting finding was that the instruction did not provide adequate training to increase knee flexion angles at initial ground contact.

One important factor that may have played a significant role in minimizing the effects of videotape augmented feedback on knee flexion angle at initial ground contact was the specificity of knee flexion instruction. Various researchers have stressed the importance of providing specific attentional cueing when providing videotape augmented feedback. The concept that the athlete’s attention needs to be focused on specific criteria by the instructor seems vital to the success of videotape augmented feedback instruction. The main goal of the movement task conveyed to each subject was to land as softly as possible. The groups that received videotape augmented feedback were told to focus on knee flexion, but the feedback was focused on overall knee range of motion during the landing phase (ie, knee angular displacement flexion angle) and not on the position of the knee at initial ground contact. The aspect of increasing knee flexion at initial ground contact was not the specified focal point of instruction, thus possibly resulting in the lack of focused attention on knee flexion angles at initial ground contact and a lack of change in landing kinematics at initial ground contact. It must be noted that attempting to excessively increase knee flexion angle at initial contact may cause less time for eccentric muscular contraction and decreased time for dissipation of contact forces, resulting in increased impact forces that possibly create injurious forces. It has been theorized by numerous ACL researchers that the mechanism of noncontact ACL injury is near the time of initial contact and that an extended stiff-legged knee position may cause increased risk for ACL. However, a balance must be obtained in determining how much knee flexion angle at initial contact from a jump is necessary to reduce risk of ACL injury, while not increasing it too much to create muscular injuries and increased impact forces. The results of this study do not support the ability to change knee flexion angles at initial foot contact; future studies should be focused on evaluating technique improvements during the most relevant “at-risk” times for ACL injury—peak proximal anterior tibial shear force typically found within the initial phases of the landing motion.

Recent investigations analyzing jump-landing technique have been limited to various non-sport-
specific types of tasks (eg, box drop-jumps, hanging free falls, or standstill countermovement jumps). The uniqueness of our investigation was the use of a simulated modified basketball-rebounding task for jump-landing instruction. There are no reported investigations in the literature that have used a goal-oriented task designed to simulate a basketball-rebounding task for the training of jump-landing technique with a 4-m run-up approach. A few researchers have used volleyball\textsuperscript{14,30} and netball,\textsuperscript{5} but the aspects of a specific basketball simulation task have been lacking. What happens to the transfer of learning proper jump-landing technique when an individual is expected to perform at a competitive level yet tries to maintain proper jump-landing form? The effects of a simulated basketball-rebounding task in a laboratory setting impose different dynamic environmental constraints as compared to jump landing during an actual basketball game, yet our results are promising as one of the preliminary steps in creating a testing situation based on sport-specific movement tasks.

An additional item of concern reflecting the altering of knee landing kinematics is the issue of whether these changes may cause increased injury potential for other knee abnormalities (eg, patellar tendinitis) or decreased athletic performance. Richards et al\textsuperscript{30} reported that increased knee flexion range of motion angles were correlated with detecting patellar tendinopathy in elite volleyball players. Of significant note was that this finding was reported in a study with a small sample size (n = 10), and it was highly correlated with high vertical impact forces. Thus, perhaps the combination of high impact forces and greater knee flexion angles creates greater risk for patellar tendon injury as opposed to high knee flexion angles alone. A future study evaluating the effects of increasing knee flexion angle during landing and its relationship to patellar tendon abnormality should be completed to further investigate this concern. Of greater concern than increasing potential patellar tendinitis incidence is the fact that increased knee flexion angles during landing may limit or decrease athletic performance. The aspect of extending landing time during a repeated basketball rebound attempt (eg, tipped ball requiring quick repetitive jump landings) is more of an issue for injury prevention. The old adage that the best method to prevent injuries is to “not play” is great for injury prevention but not for performance enhancement. The fact remains that individuals performing athletic maneuvers will not compromise performance parameters for injury prevention enhancement; thus, a fine balance needs to be found between the goals of the physically active patient and those of the sports medicine clinician. Videotape augmented feedback is a promising instructional mechanism that can be evaluated across a variety of learning tasks (eg, surgical techniques or sport skill instruction). Videotape equipment and mechanisms for analysis are quite inexpensive and readily available to most individuals. All videotape augmented feedback groups were able to significantly increase their knee angular displacement flexion angles immediately on the same day of instruction, but more important, they were able to retain the effects of instruction across a 1-week period in which no practice or instruction was provided. This result supports our initial work demonstrating that videotape augmented feedback is of significant value in immediately increasing performance capabilities and in retention of instruction across a 1-week period.

Future studies investigating the long-term effects (1 month, 6 months, 1 year, etc) of videotape augmented feedback on learning proper jump-landing technique are needed. In addition, prospective studies involving jump-landing training and the prevention of lower extremity injuries are needed to further validate the need for instructional jump-landing programs. Further research analyzing landing patterns, jump injury patterns, and various motor learning techniques is needed to provide the basis for better injury prevention programs.

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REFERENCES


