

Video Feedback and 2-Dimensional Landing Kinematics in Elite Female Handball Players

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Context: In team handball, an anterior cruciate ligament injury often occurs during landing after a jump shot. Many intervention programs try to reduce the injury rate by instructing athletes to land more safely. Video is an effective way to provide feedback, but little is known about its influence on landing technique in sport-specific situations.

Objective: To test the effectiveness of a video-overlay feedback method on landing technique in elite handball players.

Design: Controlled laboratory study.

Setting: Laboratory.

Patients or Other Participants: A total of 16 elite female handball players assigned to a control group ($n = 8$; age = 17.61 ± 1.34 years, height = 1.73 ± 0.06 m, mass = 69.55 ± 4.29 kg) or video group ($n = 8$; age = 17.81 ± 0.86 years, height = 1.71 ± 0.03 m, mass = 64.28 ± 6.29 kg).

Intervention(s): Both groups performed jump shots in a pretest, 2 training sessions, and a posttest. The video group received video feedback of an expert model with an overlay of their own jump shots in training sessions 1 and 2, whereas the control group did not.

Main Outcome Measure(s): We measured ankle, knee, and hip angles in the sagittal plane at initial contact and peak

flexion; range of motion; and Landing Error Scoring System (LESS) scores. One 2×4 repeated-measures analysis of variance was conducted to analyze the group, time, and interaction effects of all kinematic outcome measures and the LESS score.

Results: The video group improved knee and hip flexion at initial contact and peak flexion and range of motion. In addition, the group's average peak ankle flexion (12.0° at pretest to 21.8° at posttest) and LESS score (8.1 pretest to 4.0 posttest) improved. When we considered performance variables, no differences between groups were found in shot accuracy or vertical jump height, whereas horizontal jump distance in the video group increased over time.

Conclusions: Overlay visual feedback is an effective method for improving landing kinematics during a sport-specific jump shot. Further research is warranted to determine the long-term effects and transfer to training and game situations.

Key Words: anterior cruciate ligament, motor learning, injury prevention

Key Points

- The overlay visual feedback method immediately improved the jump-shot landing technique of elite female handball players.
- After video feedback, players demonstrated improved hip-, knee-, and ankle-flexion angles and Landing Error Scoring System scores, indicating a safer landing technique.
- Researchers need to determine the long-term effects of video feedback and transfer to training and games.

More than 2 million anterior cruciate ligament (ACL) injuries occur worldwide annually and result in the longest withdrawal time from sports participation.¹ The greater prevalence of ACL injury in young female athletes is a major problem in sports medicine. After rehabilitation, athletes are often unable to perform at the same level as before the injury and are at higher risk for comorbidities, such as osteoarthritis.² Therefore, the need for ACL injury prevention is clear, and effective long-term ACL injury-prevention programs are essential. Whereas many prevention programs have been developed, the incidence of ACL injuries remains high.³ Hence, further research into and development of effective long-term prevention methods are warranted.

Handball is a sport with one of the highest risks for sustaining an ACL injury.⁴ The ACL often ruptures during

noncontact single-legged landings,⁵ which involve a decreased base of support and more loading of the lower extremity than in 2-legged landings. Approximately 80% of ACL injuries in handball occur when athletes plant and cut or land after a jump shot.⁵ Within this multifactorial problem exist kinematic and kinetic sex differences that may render women more susceptible to ACL injuries than men. For example, women tend to land more stiffly than men,⁶ as characterized by less absorption at the hip, knee, and ankle joints during landing. A stiff landing technique results in a higher risk of ACL injury because the muscular energy absorption is low with high external knee-extension moments, which places greater load on the ACL.⁷ The jump shot is the most used shot in handball and is characterized by rapid deceleration on 1 lower extremity with little knee flexion and a high knee-valgus load.^{5,8} Given that landing

on 2 feet after the jump shot has been advocated to reduce the ACL injury risk,⁹ we need to understand whether jump-shot landing mechanics can be improved and if so, how.

Motor skills can be taught with instruction or feedback directed at body movements (eg, “Keep your knees over your toes,” “Land with your knees flexed,” or “Land with your feet shoulder width apart”). In the motor-learning domain, this type of attentional focus is termed *internal focus* (IF).¹⁰ Conversely, an *external focus* (EF) of attention is induced when an athlete’s attention is directed toward the outcome or effects of the movement (eg, “Imagine sitting down on a chair when landing”).¹⁰

Landing mechanics in handball players have been improved by having athletes concentrate on good movement technique^{9,11} using an IF. However, learning movement strategies with an IF has been shown to be less suitable for acquiring the complex motor skills required for sports,¹⁰ whereas an EF enhances automatic motor control.¹⁰ Compared with IF or no instruction, an EF of attention has demonstrated superior results for jump-landing performance,¹² with an improved transfer to sport.¹⁰ An effective way to stimulate learning with an EF of attention is by providing video feedback of an expert model,¹³ which can enable the participant to reproduce a correct movement pattern. A software tool, VizMo, was recently developed by one of the authors (E.O.) to create a contour overlay of the expert model movement with that of the athlete.^{14,15} In this way, athletes can directly compare their whole-body movement with the expert model’s movement and correct for the differences. Direct feedback has been suggested to enhance motor learning¹⁴ and has been explored for changing landing biomechanics.^{16,17} Given that a contour overlay encourages motor learning as a problem-solving process,¹⁸ it may result in greater learning value, but this has not been investigated.

We need to reduce the incidence of ACL injuries in elite female handball players, and implementing the VizMo software tool may contribute to ACL

injury-prevention programs. Therefore, the primary purpose of our study was to evaluate whether video feedback with an overlay method to stimulate EF effectively would improve a handball-specific landing technique that, in turn, can reduce ACL injury risk factors. By applying the EF motor-learning concept, we hypothesized that players who received video feedback would improve their landing technique compared with players who did not. The secondary objective was to investigate performance measures (ie, jump height, jump distance, and target hits), as these are important in sport-specific situations. We hypothesized that the performance measures would be maintained in the group receiving video feedback.

METHODS

Participants

Sixteen elite female handball players volunteered for this study (Table 1). All players competed in handball at the highest national level and were eligible to participate if they were at least 16 years old and had no injuries to the lower extremities at the time of the study. To ensure that players were familiar with the jump-shot task, goalkeepers were excluded from the study. Enrollment, allocation, and testing

Table 1. Characteristics of the Elite Female Handball Athletes

Characteristic	Group ^a	
	Control (n = 8) ^b	Video (n = 8) ^c
	Mean ± SD	
Age, y	17.61 ± 1.34	17.81 ± 0.86
Height, m	1.73 ± 0.06	1.71 ± 0.03
Mass, kg	69.55 ± 4.29	64.28 ± 6.29
	No.	
Hand dominance, left/right	2/6	1/7

^a No between-groups differences were observed for age, height, mass, or hand dominance.

^b Received no feedback.

^c Received feedback.

were conducted by the same investigator (W.P.). A testing schedule was created on the basis of player availability. For this testing schedule, we alternated allocation of the players to either the video or control group. All participants or their legal guardians provided written informed consent, and the study was approved by the Medical Ethical Committee of the University of Groningen (ECB/2014.1.20_1).

Data Collection

Experts. Expert videos of the jump-shot landing were obtained to provide overlay feedback to the players in the video group, so that they could compare their own trials with those of the experts. Therefore, the expert videos were obtained before the experimental study, as in recent research.^{15,19} Two professional female handball players who were not participants served as expert models. The heights of these 2 expert players were matched with the 2 height ranges in the experimental group (1.60–1.70 m and 1.70–1.80 m). We selected the videos on the basis of the landing technique of the expert players, which was measured with 3-dimensional (3D) motion analysis (Vicon Motion Analysis Systems Inc, Oxford, United Kingdom). These landing techniques met the requirements of previous researchers for a safe landing in women: (1) knee varus/valgus moment less than 22.25 Nm/kg,²⁰ (2) knee-flexion range greater than 45°,²¹ and (3) peak vertical ground reaction force equal to or less than 17.90 N/kg.²² We collected body height and mass and then 3D trajectories of twenty-one 14-mm-diameter retroreflective markers (model Plug-In Gait; Vicon Motion Analysis Systems Inc), with additional trunk markers placed on the sternum, C7, T10, and right scapula, using an 8-camera motion-analysis system (Vicon Motion Analysis Systems Inc) sampling at 200 Hz and Vicon Nexus software (version 1.8.3; Vicon Motion Analysis Systems Inc). Ground reaction force data were collected at a sampling rate of 1000 Hz using 2 force plates (Bertec Corp, Columbus, OH) embedded in the ground. Customized software (MATLAB 6.1; The MathWorks Inc, Natick, MA) was written and used to compute segmental kinematics and kinetics of the *test leg*, which was defined as the lower limb opposite the upper limb with which the participant threw a ball. Force plate and kinetic data were filtered using a fourth-order, zero-lag, low-pass Butterworth filter at 10 Hz.

Participants. After collecting and analyzing the expert data, we conducted the experimental study. For each handball player, anthropometric data were collected, and reflective markers were placed on the second metatarsal,

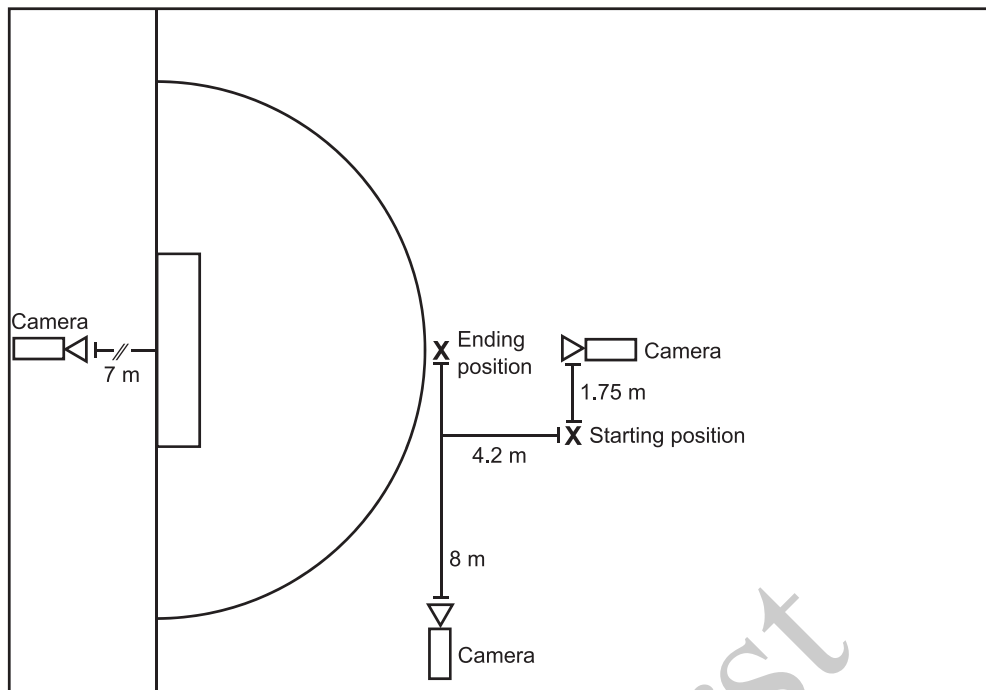


Figure 1. Camera placement during training sessions. Two cameras captured frontal-plane (placed 7 m behind the handball goal) and sagittal-plane (placed 8 m at side of test leg) views of each participant during the experiment.

distal calcaneus, lateral malleolus, lateral epicondyle of the tibia, tibial tuberosity, greater trochanter, and acromion. To obtain sagittal-plane kinematics for the test leg, markers were placed only on the left side for right-hand-dominant players and on the right side for left-hand-dominant players.

Players completed standardized warm-up exercises, which consisted of 2 minutes of jogging and several stretching exercises, and then received the general instructions for completing the test trials. We explained the jump-shot task and instructed participants to take 3 steps, jump in the air before reaching the circle, throw the handball at the goal, and land with 2 feet on the ground (Figure 1). Each player was allowed to practice the jump-shot task 5 times before data collection. After performing familiarization trials, players performed 5 standardized jump shots that were categorized as the pretest (baseline) jump shots. To assess jump-shot performance, we suspended a target standard handball in the goal with the center of the ball 0.45 m from the top bar and 0.45 m from the side bar. We placed the ball on the left side of the goal for right-hand-dominant players and on the right side for left-hand-dominant players. To ensure that the task was challenging and that their attention was not directed toward the landing, players were instructed to try to hit the target, indicating shot accuracy. All players wore black body suits (Morphsuits; AFG Media Limited, Edinburgh, Scotland) to allow the VizMo software to isolate the moving figure from the background and to create the overlay with the expert video.

After the pretest, the video group watched the expert video (positive feedback) on a television screen (model Flatron 65VS10-BAA; LG Corp, Seoul, South Korea). They were instructed that the expert model performed the landing task in the optimal way and that they should try to mimic this landing. No further instructions on their landing

techniques were provided. This procedure was repeated after every 5 trials in the training sessions, for a total of 4 times. The pretest was followed by 2 training sessions (training session 1 [TR1] and training session 2 [TR2]) of 10 trials each. In addition, the players in the video group could request feedback after each trial in TR1 and TR2 (self-controlled feedback). They were reminded of this option to choose feedback before TR1 and TR2. Feedback comprised showing the landing movement of the expert model, scaled to their body height, with an overlay of their own movement. They received the following instruction: “When you ask for feedback, a video with 2 silhouettes will appear on the screen; the red silhouette is you, and the grey one is the expert. The jump of the expert is an optimally performed jump shot. Try to imitate that jump shot of the expert as best as possible. Try to gain as much overlap as possible.” Self-controlled feedback has been shown to positively influence the motor-learning process because it is more tailored to the players’ needs and motivations than predetermined feedback schedules.²³ The overlays were achieved using the customized software VizMo (Figure 2) synchronized at the time of initial ground contact (IC) during the landing. Pilot sessions with VizMo in which the videos were presented to an independent test participant at different playing speeds revealed that the optimal playing speed was 70% of normal speed. This playing speed was subsequently used during data collection.

The control group did not receive instructions or feedback during the testing. After the 2 training sessions, 5 more trials were collected for the posttest. The pretest, TR1, TR2, and posttest were conducted on the same day. Each player was provided with enough rest between trials to reduce the potential effects of fatigue and with a 2-minute rest between sessions (pretest, TR1, TR2, and

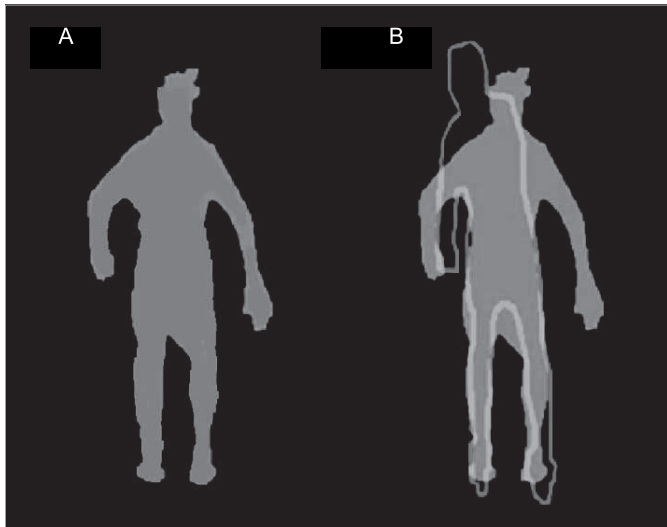


Figure 2. An example of video feedback including expert and athlete overlay during landing after the jump shot: **A**, expert landing and **B**, overlay of expert and participant (red line) technique for immediate comparison.

posttest). Elapsed time between pretest and posttest averaged 15 minutes.

Data Acquisition

To show an overlay with the expert model, every trial was recorded with a camera posterior to the player to provide footage for VizMo (Figure 1). In addition, sagittal-plane kinematic and sagittal- and frontal-plane Landing Error Scoring System (LESS) data were collected using high-speed cameras recording at 240 Hz (Biomechanics software version 21; Quintic Consultancy Ltd, Coventry, United Kingdom). Two cameras captured frontal-plane (placed 7 m behind the handball goal) and sagittal-plane (placed 8 m at the side of the test leg) views of each player during the experimental movement. Expert videos and overlay were presented on a television screen.

Kinematic analyses were conducted using the Quintic software, a reliable tool for 2-dimensional (2D) motion analysis.²⁴ The main outcome measures for the landing technique were hip, knee, and ankle angles in the sagittal plane. By convention, 0° at the hip, knee, and ankle corresponded to an erect standing posture with the trunk, thigh, and leg in a straight line and the foot at a right angle to the leg. *Hip flexion* and *ankle dorsiflexion* were defined as positive angles; *ankle plantar flexion* and *knee flexion*, as negative angles. Angles were calculated at IC and when the peak angle was attained. *Range of motion* (ROM) was defined as the difference between IC and peak flexion angles. In addition, the percentage of target hits was monitored for all 30 trials, and horizontal jump distance was measured by calculating the distance between the toe marker at the point of push off and landing for each trial. Jump height was calculated as the difference between the peak height of the lateral epicondyle of the femur marker on the test leg during the jump and the height when the player stood upright.

Each trial was analyzed and scored according to the LESS, which is a valid and reliable screening tool to identify individuals who are at risk for sustaining an ACL

injury.²¹ To simplify the scoring process, the rater (W.P.) focused on a designated test leg. Scoring was based on the presence or absence of specific landing characteristics. A total of 17 scored items on the LESS are used to analyze joint angles and landing symmetry of the landing pattern.²⁵ We collected the total LESS score and inspected it for knee-valgus angle at IC and knee-valgus displacement individually. The LESS score represents *excellent* (<4), *good* (>4 to ≤5), *moderate* (>5 to ≤6), or *poor* (>6) jump-landing technique.²⁵

Statistical Analysis

To determine between-group differences in landing kinematics (control and video groups) and time (pretest, TR1, TR2, and posttest), a 2 × 4 repeated-measures analysis of variance was conducted to analyze the group, time, and interaction effects of all kinematic outcome measures and the LESS score, with the α level set a priori at ≤.05. When differences were observed, we conducted post hoc Bonferroni comparisons. Time was the within-subject factor, and group was the between-subjects factor. Based on the number of participants and pooled standard deviation, effect sizes (ES) were calculated for all comparisons. We assessed the magnitude of the significant effects using the Cohen *d* (*small* [$d \leq 0.2$], *moderate* [$0.2 \geq d \leq 0.8$], or *large* [$d \geq 0.8$]).²⁶ Regression coefficients were calculated for the jump distance, jump height, and percentage of target hits for all 30 trials to determine change during the tests. Differences in regression coefficients between groups per performance measure were tested with independent-samples *t* tests. Statistical analyses were performed using SPSS (version 21.0.0; IBM Corp, Armonk, NY).

RESULTS

No between-groups differences in player characteristics or baseline pretest landing kinematics were found for the control and video groups (Tables 1 and 2). The means and standard deviations of the the joint-flexion angles at IC and peak, ROM, and LESS score are shown in Table 2. Effects that were different are described in this section.

Landing Technique

Hip Flexion. At IC, we observed a group × time interaction effect ($F_{1.54,21.52} = 19.73$, $P < .001$, Cohen $d = 0.59$). For the video group, hip-flexion angle at IC increased from pretest to TR1 ($P = .03$, Cohen $d = -0.68$), TR2 ($P = .005$, Cohen $d = -1.37$), and posttest ($P = .001$, Cohen $d = -1.64$). We also noted between-groups differences at TR2 ($P = .02$, Cohen $d = 0.32$) and posttest ($P = .01$, Cohen $d = 0.37$).

A group × time interaction effect for the peak hip-flexion angle was found ($F_{1.28,17.89} = 36.05$, $P < .001$, Cohen $d = 0.72$). The peak hip-flexion angle in the video group increased from pretest to TR1 ($P < .001$, Cohen $d = -2.27$), TR2 ($P < .001$, Cohen $d = -2.80$), and posttest ($P = .001$, Cohen $d = -2.62$). We also demonstrated between-groups differences at TR1 ($P = .001$, Cohen $d = 0.59$), TR2 ($P < .001$, Cohen $d = 0.73$), and posttest ($P < .001$, Cohen $d = 0.72$).

The changes in hip-flexion ROM over time for both groups are shown in Figure 3. A group × time interaction

Table 2. Joint Flexion Angles, Range of Motion, and Landing Error Scoring System Score

Variable	Group ^a										P Value	F Value	Effect Size	
	Control					Video								
	Pretest	Training Session 1	Training Session 2	Posttest	Pretest	Training Session 1	Training Session 2	Posttest						
Initial contact, °														
Hip flexion	32.7 ± 6.2	30.2 ± 6.4	28.4 ± 7.2	28.7 ± 7.6	29.7 ± 4.4	33.0 ± 5.3	37.2 ± 6.4	38.7 ± 6.4	<.001 ^b	19.73	0.59			
Knee flexion	-15.1 ± 4.1	-14.4 ± 4.6	-13.8 ± 4.1	-13.6 ± 4.0	-12.4 ± 3.9	-14.2 ± 3.2	-17.4 ± 3.5	-17.3 ± 2.4	.004 ^b	9.43	0.40			
Ankle flexion	-21.4 ± 14.0	-20.6 ± 14.1	-19.9 ± 12.3	-20.3 ± 12.7	-20.7 ± 15.3	-15.2 ± 20.2	-14.2 ± 19.4	-13.7 ± 19.1	.20	1.76	0.11			
Peak value, °														
Hip flexion	64.0 ± 11.3	60.2 ± 10.6	55.7 ± 10.9	53.4 ± 11.4	58.9 ± 11.4	88.4 ± 14.4	98.5 ± 16.4	97.8 ± 17.6	<.001 ^b	36.05	0.72			
Knee flexion	-73.6 ± 4.0	-72.0 ± 4.5	-69.7 ± 5.4	-68.9 ± 5.9	-70.4 ± 2.8	-94.3 ± 8.5	-99.7 ± 10.3	-99.6 ± 11.3	<.001 ^b	52.44	0.79			
Ankle flexion	11.7 ± 3.5	12.0 ± 3.8	11.2 ± 3.6	11.8 ± 3.2	12.0 ± 2.3	19.2 ± 5.3	22.1 ± 6.1	21.8 ± 5.8	<.001 ^b	19.76	0.59			
Range of motion, °														
Hip flexion	35.6 ± 13.0	30.0 ± 6.9	27.3 ± 6.1	27.5 ± 12.3	31.6 ± 12.5	55.4 ± 13.4	61.3 ± 13.9	63.9 ± 11.7	<.001 ^b	16.45	0.54			
Knee flexion	-58.6 ± 4.3	-57.8 ± 3.9	-55.9 ± 4.4	-53.8 ± 7.1	-58.1 ± 5.3	-80.0 ± 8.7	-82.3 ± 10.5	-82.3 ± 10.5	<.001 ^b	33.55	0.71			
Ankle flexion	32.7 ± 12.0	32.7 ± 11.7	31.5 ± 11.3	32.1 ± 11.9	33.7 ± 13.8	34.6 ± 22.4	36.3 ± 22.3	40.3 ± 18.0	.26	1.42	0.09			
Landing Error Scoring System score ^c	8.0 ± 0.4	7.9 ± 0.4	8.2 ± 0.4	8.1 ± 0.3	8.1 ± 0.7	5.0 ± 1.2	4.2 ± 1.2	4.0 ± 1.3	<.001 ^b	8.83	0.84			

^a No between-groups difference were found in pretest kinematics.

^b Group × time interaction effect ($P < .05$).

^c The mean cumulative score per group of 17 scored items.

effect was present for hip-flexion ROM ($F_{2,24,31.42} = 16.45$, $P < .001$, Cohen $d = 0.54$). In the video group, hip-flexion ROM increased from pretest to TR1 ($P = .001$, Cohen $d = -1.84$), TR2 ($P = .001$, Cohen $d = -2.25$), and posttest ($P = .003$, Cohen $d = -2.67$). We also observed between-groups differences at TR1 ($P < .001$, Cohen $d = 0.62$), TR2 ($P < .001$, Cohen $d = 0.74$), and posttest ($P < .001$, Cohen $d = 0.73$).

Knee Flexion. We noted an interaction effect for knee-flexion angle at IC ($F_{1,28,17.88} = 9.43$, $P = .004$, Cohen $d = 0.40$). The control group showed a small decrease in knee-flexion angle at IC, whereas the angle increased over time in the video group from pretest to TR1 ($P = .01$, Cohen $d = 0.53$), TR2 ($P = .03$, Cohen $d = 1.36$), and posttest ($P = .03$, Cohen $d = 1.52$). A between-groups difference for knee-flexion angle at IC was found at posttest ($P = .04$, Cohen $d = 0.27$).

A similar interaction effect was present for the peak knee-flexion angle. We observed a group × time interaction effect ($F_{1,34,18.82} = 52.44$, $P < .001$, Cohen $d = 0.79$). In the video group, peak knee-flexion angle increased over time from pretest to TR1 ($P < .001$, Cohen $d = 3.77$), TR2 ($P < .001$, Cohen $d = 3.87$), and posttest ($P < .001$, Cohen $d = 3.54$). We also detected between-groups differences at TR1 ($P < .001$, Cohen $d = 0.75$), TR2 ($P < .001$, Cohen $d = 0.79$), and posttest ($P < .001$, Cohen $d = 0.77$).

For knee-flexion ROM, a group × time interaction effect was evident ($F_{1,43,20.05} = 33.55$, $P < .001$, Cohen $d = 0.71$). In the video group, the pretest knee-flexion ROM was smaller than at TR1 ($P < .001$, Cohen $d = 3.05$), TR2 ($P < .001$, Cohen $d = 2.91$), and posttest ($P < .001$, Cohen $d = 2.91$). We also found between-groups differences at TR1 ($P < .001$, Cohen $d = 0.76$), TR2 ($P < .001$, Cohen $d = 0.75$), and posttest ($P < .001$, Cohen $d = 0.74$). The changes in knee ROM over time for both groups are shown in Figure 3.

Ankle Flexion. No time, group, or interaction effects were found for the ankle-flexion angle at IC and ROM. The peak ankle-flexion angle increased in the video group but not in the control group, indicating a group × time interaction effect ($F_{1,86,25.96} = 19.76$, $P < .001$, Cohen $d = 0.59$). In the video group, peak ankle-flexion increased from pretest to TR1 ($P = .004$, Cohen $d = -1.78$), TR2 ($P = .001$, Cohen $d = -2.18$), and posttest ($P = .001$, Cohen $d = -2.21$). We also saw between-groups differences at TR1 ($P = .008$, Cohen $d = 0.40$), TR2 ($P = .001$, Cohen $d = 0.57$), and posttest ($P = .001$, Cohen $d = 0.56$). The changes in ankle ROM over time for both groups are shown in Figure 3.

LESS Score. We demonstrated a group × time interaction effect ($F_{2,29,32.10} = 8.83$, $P < .001$, Cohen $d = 0.84$) for the LESS score. For the video group, the LESS score improved from pretest to TR1 ($P < .001$, Cohen $d = 3.16$), TR2 ($P < .001$, Cohen $d = 3.97$), and posttest ($P < .001$, Cohen $d = 3.93$). For the individual item knee-valgus angle at IC, the score decreased in the video group ($0.50 ± 1.07$ at pretest to $0.13 ± 0.35$ at posttest) but remained constant in the control group ($1.00 ± 0.92$ pretest to $0.63 ± 0.74$ posttest). Similarly, for the item knee-valgus displacement, the score decreased in the video group ($2.13 ± 1.64$ at pretest to $0.25 ± 0.46$ at posttest) but remained constant in the control group ($1.63 ± 1.51$ at pretest to $1.75 ± 1.83$ at posttest).

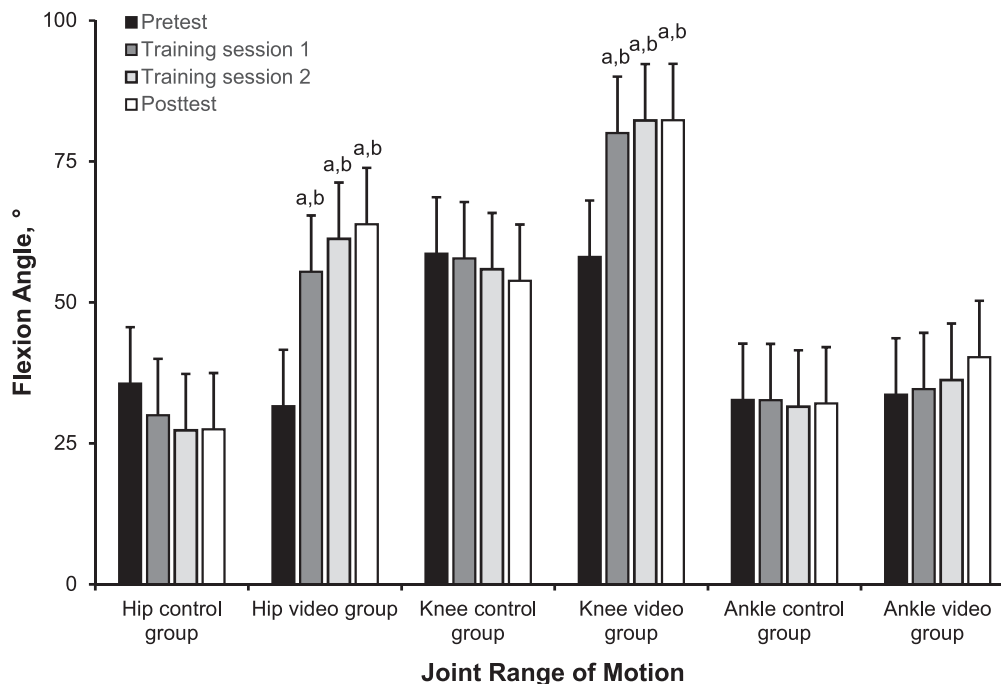


Figure 3. Changes in hip, knee, and ankle range of motion over time for both groups.^a Different from pretest ($P < .05$).^b Between-groups difference ($P < .05$). Knee flexion is converted to positive in this figure for display purposes.

Performance

Horizontal Jump Distance. Jump distance decreased in the control group and increased in the video group over all trials. The change between the control and video groups was different ($t_{14} = 2.48, P = .03$; Table 3).

Vertical Jump Height. Peak jump height decreased in both groups, but the decrease was not different between groups ($t_{14} = 1.45, P = .17$; Table 3).

Target Hitting. We noted no between-groups differences in the percentage of times the target was hit during the trials ($t_{14} = 1.18, P = .26$; Table 3).

DISCUSSION

The primary purpose of our study was to investigate whether video-overlay feedback improved landing technique after a jump shot in elite female handball players. The video group improved their hip, knee, and ankle flexion and LESS score and maintained their jump-shot performance, suggesting that video overlay provides an effective method for improving landing technique. How these improvements may assist in reducing the risk of ACL injuries is outlined in this section.

Hip-flexion angle at IC, peak flexion, and ROM showed large improvements in the video group, whereas hip-flexion angle at TR1, TR2, and the posttest did not change in the control group. The increase in hip flexion due to video feedback is in line with another study²⁷ in which researchers reported increased hip-flexion angles after participants received video feedback with added IF components. Blackburn and Padua²⁸ suggested that increasing hip flexion results in the center of mass moving more anteriorly, producing a safer center-of-mass position with less load on the ACL by reducing the demand on the quadriceps. In addition, due to increased hip flexion, knee flexion often increases, which is favorable for loads on the ACL.²⁹

Olsen et al⁵ reported that landing after a jump shot with the knee near full extension was an important ACL injury mechanism in team handball players. To counteract rapid flexion of the joints during the impact of a landing, internal knee-extension moments must be generated. The amount of knee flexion is a predictor for energy absorption during impact; when the knee-flexion angle is smaller, less energy is absorbed by the knee muscles, which increases the ACL load.⁷ In our study, the video group increased knee-flexion angle from pretest to posttest. In TR1, the knee-flexion

Table 3. Performance Variables Over All Trials

Variable	Group				P Value	t_{14} Value
	Control		Video			
	Mean \pm SD	Regression ^a	Mean \pm SD	Regression ^a		
Horizontal jump distance, m	1.58 \pm 0.16	-0.58 \pm 0.64	1.64 \pm 0.31	0.34 \pm 0.83	.03 ^{b,c}	2.48
Vertical jump height, m	0.37 \pm 0.08	-0.98 \pm 1.03	0.36 \pm 0.04	-0.26 \pm 0.96	.17	1.45
Target hits, %	32.91 \pm 14.94	-0.07 \pm 0.37	38.34 \pm 14.08	0.20 \pm 0.53	.26	1.18

^a Regression slopes indicate the increase or decrease during all 30 trials (pretest, training session 1, training session 2, and posttest).

^b Difference between regression coefficient of control and video groups ($P < .05$).

^c A greater horizontal jump distance was observed in the video group than in the control group.

angle at IC and peak knee-flexion angle increased. This resulted in increased knee-flexion ROM until TR2 that was maintained at the posttest, suggesting that 1 training session with comparative feedback during 10 jump shots was sufficient to positively influence knee flexion during landings. These findings are in line with those of other studies^{13,27} in which visual feedback was associated with increased knee-flexion angle and ROM; this result is encouraging because increased knee flexion may reduce the risk of ACL injury.

Both the control and video groups showed a small reduction in ankle plantar flexion at IC from pretest to posttest. The reduction was greater in the video group, but the effects were not different, probably due to a change in the landing strategy of 2 players in the video group: during TR1 and TR2, they changed from a toe-to-heel landing to a heel-to-toe landing style. The change from a toe-to-heel landing style was not observed in any of the other players. The expert videos displayed a toe-landing strategy and, therefore, were unlikely to be the cause of the change in landing strategy of these 2 players. The peak ankle-dorsiflexion angle and resulting ankle-flexion ROM did increase over time in the video group but not in the control group. A forefoot type of landing, resulting in more flexion of the ankle joint during the landing phase, has a role in energy absorption and appears to reduce the vertical ground reaction force and the forces on the ACL.³⁰

The mean LESS score improved over time in the video group but did not change in the control group. The LESS is an effective tool for determining ACL injury risk, and individuals with LESS scores of 5 or more may be targeted for ACL injury-prevention programs.²¹ The fact that the video group was able to improve its LESS score from 8.1 at pretest to 4.0 at posttest indicates that this type of feedback effectively changed the players' technique from high to low risk, which is an encouraging step in developing injury-prevention programs.

From the increase in hip-, knee-, and ankle-flexion angle and ROM and the decrease in LESS score in the video group, we conclude that training with a video system, such as VizMo, was an effective way to change from a stiff to a softer landing technique. It is intriguing that the video the participants watched depicted them from a posterior view. The feedback resulted in effective changes in sagittal-plane technique, which was where the greatest movements occurred and, therefore, was more easily comparable. From these height differences in downward movement from IC to peak knee flexion (and the direct comparison with their own height differences), the participants implicitly inferred their hip or knee angles. In other words, from the 2D contour, by way of mirror neurons, players automatically created a natural 3D body image.

The impact time is longer during a soft than a stiff landing; therefore, the peak ground reaction force will potentially be lower, which results in less loading of the ACL.³¹ However, we did not include a frontal-plane analysis in this study. Although a soft-landing strategy was adopted in the video group, it is still vital to know the knee-valgus angles because the direction of the vertical ground reaction force (moment arm) greatly affects the maximum knee-abduction moment.³² We did, however, collect LESS scores and inspected knee valgus at IC and knee-valgus displacement individually. First, the knee-

valgus score at IC decreased from 0.50 ± 1.07 at pretest to 0.13 ± 0.35 at posttest in the video group, whereas it stayed constant in the control group, from 1.00 ± 0.92 at pretest to 0.63 ± 0.74 at posttest. For knee-valgus displacement, the same pattern was seen. The video group decreased its LESS score from 2.13 ± 1.64 at pretest to 0.25 ± 0.46 at posttest, whereas the score stayed constant in the control group, from 1.63 ± 1.51 at pretest to 1.75 ± 1.83 at posttest.

During landing tasks, the preferred landing style of women is often a stiff technique.⁶ This is in line with the landing style of the players in the control group and with the pretest of the video group. The reason that women prefer a stiff instead of a soft landing technique might be the higher energy cost of soft landings, which can reduce performance. To monitor performance, we analyzed horizontal jump distance, vertical jump height, and shot accuracy. No between-groups differences were found in shot accuracy or vertical jump height, which is important because the players were apparently able to maintain shot accuracy and jump height while improving landing technique. Horizontal jump distance in the video group increased over time compared with the control group. This indicates that landing technique was improved, while performance was maintained or even improved.

Self-Controlled Feedback

For effective motor learning and performance, the feedback frequency is less important than the learner's ability to choose, or not choose, feedback.^{10,33} This self-controlled feedback, as used in our study, led to more effective learning than predetermined feedback schedules.^{10,33} Chen et al³⁴ also found that self-initiated knowledge of results was more effective than passively received knowledge of results. In our study, the video group requested a relatively small amount of feedback (1.50 ± 0.76 times in TR1 and 0.88 ± 0.83 times in TR2). This supports the results of Janelle et al,³⁵ who found that, when given the opportunity to control the feedback environment, learners required relatively less feedback to acquire and retain skills at a level equivalent to or surpassing those who were given more feedback but received it passively.

Study Limitations and Further Research

Our findings may be limited to this specific population of elite athletes and may not translate to other populations, such as recreational or younger athletes. The results are also task specific, and the effect of overlay feedback on technique in tasks such as single-legged landings and sidestep cutting has not been determined.

Given that the kinematic values were obtained through 2D video analysis, the observations should be interpreted with caution. However, whereas most authors to date have used 3D methods to assess lower limb kinematics, 2D video analysis has become more common because of its greater practicality and good to excellent reliability (intraclass correlation coefficient = 0.72–0.91) between sessions with a 1-week interval.³⁶

Furthermore, no conclusions based on kinematic data can be drawn on the effect of the video feedback in the frontal plane and especially for knee-valgus angle. However, the LESS score showed that the frontal-plane knee biomechan-

ics improved, reflecting enhancement of whole-body technique. This is an important risk factor, and further research should be conducted to validate whether video-overlay feedback, such as that offered by VizMo, can effectively improve lower extremity frontal-plane kinematics and kinetics. Whereas strong positive influences on this sport-specific landing technique were found using the video feedback in a single training session, we do not know whether similar results would occur during a retention test or an actual game situation. To ascertain whether the changes in landing technique are maintained over time on the field, transfer and retention tests are needed. Research in this area is promising.^{15,19}

In addition, considering our access to this elite group of 16 female athletes, which ensured enough power, 2 groups were compared. It would have been ideal to also include other forms of feedback for comparison with this overlay technique. Yet we believe that our results are clinically relevant, given that the increased ROM is favorable for absorbing energy and, therefore, lowering the risk of ACL injury.

Last, the LESS was originally developed for a drop-landing task followed by a vertical jump²⁵; however, we believe it is valuable to score the landing after a jump because this is when ACL injuries frequently occur.⁵ Whereas no plyometric action is required after the jump shot, the jump shot still has its strenuous components because it is preceded by a complex interaction of movements while running, jumping, shooting, and landing. Landing on 2 feet after the jump shot has been advocated to reduce ACL injury risk⁹ and the LESS is a validated tool,²⁵ so we used the LESS score to indicate technique. Nevertheless, no firm conclusions can be drawn about the exact validity of the LESS test for the jump shot. For example, the jump shot involves more forward movement than the original double-legged jump-landing technique described by Padua et al.²⁵ This increased forward movement can change the perspective of the camera relative to the participant. Yet landing technique clearly improved, which indicates the value of the LESS during this task. Further research is needed to determine what cutoff score would apply for a landing task, such as after the jump shot in handball. In addition, further investigation is needed to validate this tool for different tasks using 3D motion-analysis techniques.

CONCLUSIONS

The video overlay technique was effective in immediately improving jump-shot landing technique in elite female handball players. Players who received the video feedback showed improvements in hip-, knee-, and ankle-flexion angles and the LESS score, reflecting a safer landing technique. After the video feedback, their landing technique became less stiff and, therefore, potentially safer, while performance was maintained or even improved. We recommend to athletic trainers and coaches that video feedback become part of their regular training regimens when teaching players technical skills. Video overlay can be an effective method for assisting players in identifying optimal individual movement patterns. Learning while using video feedback of whole-body movement could effectively guide the athlete to reach a level of high performance and a

low chance of injury. The small investment in equipment and time for injury prevention could benefit female handball players substantially in the long term. Further research is needed to determine the long-term effects of video feedback, the transfer to actual games and training situations, and the effects in less-skilled populations.

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