INNOVATIVE VIDEO FEEDBACK ON JUMP LANDING IMPROVES LANDING TECHNIQUE IN MALES

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ABSTRACT

Video feedback may be a powerful tool to change biomechanical landing patterns associated with anterior cruciate ligament (ACL) injury risk. This study investigated the effect of video feedback on drop vertical jump (DVJ) landing strategies in team sport athletes. Fifty-nine athletes were assigned to a video feedback (VI) or control (CTRL) group. A pretest, two training sessions and a posttest were conducted. In both training sessions, video feedback, consisting of a video of the athlete’s contour superimposed onto an expert’s contour performing the DVJ landing task, was provided to the VI group; the CTRL group did not receive feedback. Outcomes included: kinematics and kinetics at peak knee valgus/varus moment during pre- and posttest and percentage overlap of expert and athlete during the training sessions. At posttest, males in the VI group showed greater hip flexion angles (p=0.001) and range of motion (p<0.001), smaller vertical ground reaction force and smaller ankle dorsiflexion moment (p<0.001) compared to pretest. At posttest, males in the VI group demonstrated smaller vertical ground reaction force (p=0.031) and ankle dorsiflexion moment (p=0.001) compared to males in the CTRL group. The VI group increased percentage overlap with the expert during training sessions and from start of first to end of second training session (p<0.001). Overall, video feedback was effective to modify landing strategies favorably in males. While females imitated the expert model, their landing strategy did not change significantly. Females may need additional (verbal) feedback to benefit from video feedback.
INTRODUCTION

A high number of anterior cruciate ligament (ACL) injuries have been reported for male and female athletes.\textsuperscript{1-4} As female athletes are at higher risk to tear their ACL than male athletes,\textsuperscript{5} a large part of ACL injury prevention research has primarily focused on female athletes. Still, the number of ACL injuries in male athletes is considerably high, suggesting that sex specific risk factors and injury prevention programs need to be determined.\textsuperscript{6} A recent systematic review reported that abnormal landing patterns, such as a high knee valgus moment, increase the risk of an ACL injury for females.\textsuperscript{7} For instance, females with an ACL injury demonstrated a 2.5 times greater knee valgus moment compared to uninjured females.\textsuperscript{8} A suggested characteristic of proper landing technique in males and females is a soft landing.\textsuperscript{9,10} Based on high ACL injury incidence rates, injury prevention programs should be recommended for both male and female athletes. However, it remains unclear which specific injury prevention strategies may be effective for males since previous studies have primarily focused on neuromuscular and biomechanical risk factors for the female athlete.\textsuperscript{11,12}

The use of instructions or feedback are effective methods to promote the learning of new movement patterns, such as jump and landing techniques.\textsuperscript{13,14} Different types of attentional focus (i.e., internal and external) have been suggested for effectively learning new movement patterns.\textsuperscript{15} Internal focus instructions primarily targets on how to perform the landing task (“bend your knees”).\textsuperscript{16} Whereas external focus instructions directs the participant’s attention on the movement effect (“land softly”).\textsuperscript{16} Most ACL injury prevention programs have primarily used internal focus instructions to teach desired landing patterns.\textsuperscript{17-19} Despite the success with these programs, an internal focus may interfere with the automaticity of the movement task and increase the conscious awareness of movements.\textsuperscript{20} This can result in increased reliance on cortical and visual feedback control of the movement, thereby affecting the athlete’s reaction on changes in the environment and ability to make unexpected movements.\textsuperscript{21} External focus stimulates automatic learning processes,\textsuperscript{15} which can improve the transfer of learning correct landing patterns from a training session to the field. There are several modes to deliver instructions with an external focus with video being one of these methods.\textsuperscript{22} Video feedback focuses its attention on the target movement pattern, with the goal of externally focusing on whole body movements rather than specific components of it.\textsuperscript{23}

Video feedback encourages the athlete to imitate observed movements by triggering the mirror neuron system,\textsuperscript{24} therefore it can be a helpful tool to learn safe
landing patterns. Previous research employing video feedback to improve landing technique have found immediate positive results in terms of an increase of knee and hip flexion angle and a decrease of peak vertical ground reaction force (vGRF), frontal plane projection and contact time.\textsuperscript{25-28} Further, one study found improved landing technique expressed by the landing error scoring system (LESS) after expert video feedback during short-term retention tests.\textsuperscript{29} Therefore, video feedback, including expert video or expert combined with self-video feedback, with or without verbal instructions resulted in a softer landing technique. The video feedback interventions described above included one session of video feedback and no data was collected during this single session. Data on landing technique during video feedback sessions could assist in understanding the learning process and evaluating these data over more training sessions could indicate if the learned landing technique was retained.\textsuperscript{30}

In the studies using both expert and self-video feedback, the videos were shown apart from each other. However, to the best of our knowledge none of the studies using video feedback showed the expert’s and athlete’s landing simultaneously. Concurrent visualization of expert and self-landing, could be beneficial due to direct synchronized comparison of the two movements. To allow direct comparison with an expert model, an innovative motor learning application called visualization of motion feedback tool (VizMo) was developed.\textsuperscript{30} This application is unique since it synchronizes in real time the two videos (expert and athlete), projects an overlay of the body contours of the expert and the athlete and calculates a percentage overlap of the two filled contours or silhouettes.\textsuperscript{31}

Therefore, the first purpose of this study was to analyze the effect of video feedback with overlay method on overlap of athlete and expert contours in male and female team sport athletes during training sessions while performing a drop vertical jump (DVJ). The second purpose was to evaluate the effect of video feedback on DVJ landing strategies in male and female team sport athletes from pre- to posttest. The hypothesis was that for male and female athletes the amount of overlap of the athlete’s and expert’s contours would increase during and between training sessions, and that landing technique would change from pre- to posttest as a result of the video feedback training.


**METHODS**

**Experimental Approach to the Problem**

A randomized controlled trial was conducted to assess the effectiveness of real-time video feedback on landing technique. Participants were randomly assigned to a video (VI) and a control (CTRL) group. The athletes started with a pretest followed by two training sessions (TR1 and TR2) and a posttest. One week was scheduled between each session (pre, TR1, TR2 and post). A 4 (time) x 2 (group) x 2 (sex) between-subjects and within-subjects design was used to evaluate overlap of athlete and expert contours during training sessions. The start and end of TR1 and TR2 were included as the 4 time points. Additionally, a 2 (time) x 2 (group) x 2 (sex) between-subjects and within-subjects design was used to examine differences in kinematics and kinetics on pre- and posttest.

**Subjects**

Based on previous research, an effect size of 0.25 is indicated as a medium effect size in an analysis of variance (ANOVA). With alpha set at 0.05 and to attain a power of 80%, a sample size of 48 participants was deemed appropriate. To account for potential study attrition, initially 40 male and 40 female athletes were recruited from local teams (basketball, handball, korfball and soccer). Korfball is a sport comparable to netball. Inclusion criteria were: (1) ≥18 years, (2) practice two to three times a week at recreational level. Exclusion criteria were: (1) a current injury to the lower extremities, (2) a history of an ACL injury or (3) an injury occurring between the pre- and posttest. All athletes signed an informed consent form and approval was granted in accordance with ethical standards of the local medical ethical committee, and as required by the journal, conforming to the Helsinki Declaration. The first author randomly allocated the male and female athletes to the CTRL and VI group, based on the order of inclusion, and was therefore not blinded to group allocation. The CONSORT flowchart describing the enrollment, allocation, follow-up and analysis can be seen in Figure 6.1. Twenty-one athletes were excluded. Therefore, fifty-nine athletes were included in the analysis (14 males VI group, 23.2 ± 3.1 years, 189.6 ± 7.4 cm, 82.1 ± 11.7 kg; 15 males CTRL group, 24.2 ± 4.0 years, 190.5 ± 5.8 cm, 80.3 ± 5.8 kg; 15 females VI group, 22.4 ± 2.5 years, 172.0 ± 7.2 cm, 64.7 ± 7.8 kg; 15 females CTRL group, 22.3 ± 3.2 years, 175.1 ± 4.9 cm, 65.1 ± 5.5 kg).
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**Procedures**

*Pre- and posttest*

At first, athletes’ body mass and height were collected. Athletes wore black, tight shorts, and additionally female athletes wore a black tight top. Sixteen reflective markers were placed on the lower body according to the Vicon Plug-in-Gait model (Vicon Motion Systems, Inc., Centennial, CO), and five markers were placed on the trunk; sternum, clavicle, C7, T10 and right scapula. Trajectory data were collected using an eight camera motion analysis system at 200 Hz (Vicon Motion Systems, Inc., Centennial, CO) and Vicon Nexus Software (Version 1.6, Vicon Motion Systems, Inc., Centennial, CO). Two Bertec force plates (Bertec Corporation, Columbus, OH) were used to collect ground reaction force data at 1000 Hz. A warming-up protocol was performed including five minutes on a bicycle ergometer (Excalibur Sport, Lode B.V., Groningen, The Netherlands) (females: 70-100W; males 100-130W), three squats, three lunges per leg and three jumps (all unloaded).

For the DVJ, athletes started on a 30 cm high box. The distance between the box and the forceplates was 50% of the athlete’s body height. The general instruction was: ‘Jump from the box onto the forceplates, and then jump as high as possible immediately after landing’. The DVJ was correct if the subject jumped from the box with two feet, if the subject jumped forward (not vertically) towards the force plates, if both feet landed entirely on the force plate and if the DVJ was performed fluidly. After practicing two to four DVJ’s, athletes performed five correct DVJ’s of which kinematics and kinetics of the lower extremity were collected.
Innovative video feedback on jump landing improves landing technique in males.

**Figure 6.1.** Flow chart describing exclusion of athletes along enrollment, allocation, follow-up and analysis.

**TR1 and TR2**

Prior to the start of this research project a software package called VizMo was developed which is described elsewhere. Briefly, this application was used to provide video feedback to athletes. The innovative character of VizMo is that it is able to superimpose the moving contour of an athlete over the moving filled contour of an expert movement. The set-up during the training sessions is shown in Figure 6.2. For the feedback, the expert video was matched with sex and height of the athlete.
Figure 6.2. Camera placement during training sessions. A webcam camera on a tripod, a large screen, a laptop with VizMo software and a transparent box were needed. Distance between camera and box was 500 cm. Height of the camera was 140 cm. The transparent box was 30 cm high. Jump distance was 50% of the athlete's body height. Adapted from Benjaminse et al. (2015).

Table 6.1. Reference values of expert performance during the DVJ

<table>
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<th>Reference value</th>
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<tr>
<td>Peak knee valgus moment</td>
<td>&lt; 22.25 Nm · kg⁻¹ females ³⁸</td>
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<tr>
<td>Knee flexion range</td>
<td>&gt; 45° males and females ³⁶</td>
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<tr>
<td>Peak VGRF</td>
<td>Females: &lt; 17.90 N · kg⁻¹ ⁸</td>
</tr>
<tr>
<td></td>
<td>Males: &lt; 59.15 N · kg⁻¹ ³⁷</td>
</tr>
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</table>

The experts were athletes who showed optimal performance of a DVJ during previous data collections. Landing technique during a DVJ of these experts was measured and all experts met pre-set reference values, these values were based on literature on (potential) risk factors for ACL injuries (Table 6.1) ⁸,¹⁸,³⁶,³⁷ In addition, videos of two
female experts (165-175 cm and 175-185 cm) and three male experts (170-180 cm; 180-190 cm; 190-200 cm) performing a DVJ were recorded using VizMo. The athletes wore long tights and a long sleeve shirt to cover their legs and arms during the two training sessions. After the previously described warm-up, instructions provided prior to pretest for the DVJ were repeated for both groups and the athletes performed fifteen jumps. The videos of the athletes were recorded from posterior view and the athletes in the VI group were allowed to receive video feedback eight times. The athletes were free to ask for feedback when needed. The athletes in the VI group received the following instruction: “A video with two 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. Try to imitate the jump of the expert as best as possible. Try to gain as much overlap as possible. Focus on your whole body movement, particularly during landing. You will perform fifteen jumps. You can choose after which jump you would like to see the overlap video for a maximum of eight times. After each jump you can let us know if you would like to see the feedback or not.” Figure 6.3 presents an example of the expert and athlete overlay during different stages of the DVJ. The video was presented on a large TV screen (LG, Flatron 65VS10-BAA) and athletes watched the video while looking in the same direction as they did during execution of the task in order to stimulate a realistic feeling and whole body awareness (embodied cognition). The athletes in the CTRL group did not receive any additional instructions. Pilot sessions with VizMo where the videos were presented to an independent test subject, at different playing speeds, revealed that the most optimal playing speed was 70% of normal speed. The preference of the test subject was taken into account as well as the duration of the video.

Figure 6.3. An example of video feedback including expert and athlete overlay during different stages of a drop vertical jump.
Data reduction
The VizMo software calculated the percentage overlap of the contours of the expert and the athlete while performing the DVJ. A 100% overlap means the athlete and the expert match perfectly. Moreover, trial-to-trial variability in percentage overlap on the 15 jumps each session was assumed beneficial for learning. The amount of percentage overlap that the athlete demonstrated at the start and at the end of TR1 and TR2 was collected and used as an outcome measure in order to analyze retention and changes over time.

A custom made Matlab (The MathWorks, Natick, MA) program was used to calculate pre- and posttest hip, knee and ankle joint kinetics and kinematics for the pre- and posttest including vGRF, sagittal hip, knee and ankle angles, moments and range of motion (RoM) and frontal knee moments. This method was reported previously. All these variables are expressed at peak knee valgus/varus moment. RoM was calculated as the joint angle at peak external valgus/varus moment minus the joint angle at initial contact. Moments were expressed as external moments and these moments and vGRF were normalized to body weight.

Statistical analyses
Means and SDs of percentage overlap at start and end of TR1 and TR2 were calculated. Furthermore, means, SD’s and 95% confidence intervals (CI) for each group were calculated for biomechanical outcome variables at pre- and posttest. A repeated measures ANOVA, with four time points (start TR1, end TR1, start TR2 and end TR2), group (VI and CTRL) and sex (male and female), was used to determine the effect of video feedback on the percentage overlap during training sessions. Further, to determine differences in biomechanics collected at pre- and posttest, separate time (pre- and posttest) x group (VI and CTRL) x sex repeated measures ANOVA were conducted for each biomechanical outcome variable. Alpha level was set at $\alpha \leq 0.05$ a priori. Post-hoc tests were performed; the p-values for both ANOVAs was adjusted using Bonferroni corrections for multiple comparisons and the adjusted p-values are presented. Cohen’s $d$ effect size was calculated for main and interaction effects. For post-hoc comparisons, it was determined where differences exist and p-value and Cohen’s $d$ are reported. Cohen’s $d$ of $0.2 \leq d \leq 0.5$, $0.5 \leq d \leq 0.8$ and $d \geq 0.8$ represent a small, moderate and large effect, respectively. SPSS 20.0 Statistical Package (SPSS Inc., Chicago) was used to analyze all data.
RESULTS

Percentage overlap
The percentage overlap for males and females in the VI and CTRL group at the start and end of TR1 and TR2 is depicted in Figure 6.4. No significant interaction effect of time, group and sex was found. A significant interaction effect of time and group was reported ($F_{2,55,140.32}=4.92, p=0.005$). Post-hoc comparisons demonstrated a larger percentage overlap for the VI group than the CTRL group at the end of TR1 ($p=0.004, ES=0.80$) and TR2 ($p=0.007, ES=0.71$). The VI group increased percentage overlap from the start to the end of TR1 ($p<0.001, ES=0.64$) and from the start of TR1 to the end of TR2 ($p<0.001, ES=0.61$). From the end of TR1 to the start of TR2 the percentage overlap decreased for the VI group ($p=0.002, ES=0.48$). After that, the percentage overlap increased in the VI group from start of TR2 to end of TR2 ($p<0.001, ES=0.46$). In the VI group no significant difference was found between start of TR1 and start of TR2 ($p=0.28$).

Figure 6.4. Percentage overlap of athlete and expert performance at start and end of each training session presented for (a) females and (b) males in CTRL and VI group. The area surrounding the percentage of overlap means corresponds with the standard deviations at these time points.
Abbreviations: CTRL = control group; VI = video feedback group; F = female; M = male; TR1 = training session 1; TR2 = training session 2

Biomechanical Variables
The descriptive statistics for the drop vertical jump were calculated (Appendix). All kinematics and kinetics are expressed at peak knee valgus or varus moment. No significant main effect of group and no significant interaction effect of time and sex was found ($p>0.05$), therefore these results are not presented. The interaction effects for group, time and sex with post-hoc analyses are presented in detail.

Significant interaction effects were found for group, time and sex for hip flexion angle ($F_{1.55}=7.78, p=0.007$) and hip flexion RoM ($F_{1.55}=4.31, p=0.043$), ankle
dorsiflexion moment ($F_{1,55}=8.71, p=0.005$), ankle dorsiflexion angle ($F_{1,55}=4.33, p=0.042$) and vGRF ($F_{1,55}=4.29, p=0.043$) (Figure 6.5). Post hoc analyses showed that the males in the VI group, increased hip flexion angle ($p=0.001, ES=0.94$) and hip flexion RoM ($p<0.001, ES=1.27$) and decreased vGRF ($p<0.001, ES=0.83$) and ankle dorsiflexion moment ($p<0.001, ES=1.00$) from pre- to posttest. The ankle dorsiflexion angle decreased in this group as well, however this decrease was not significant ($p=0.058$). Moreover, at posttest, the males in the VI group demonstrated a lower vGRF ($p=0.031, ES=0.75$) and a lower ankle dorsiflexion moment ($p=0.001, ES=1.04$) than the CTRL group. Finally, for the VI and CTRL group at pre- and posttest, larger vGRF was found for male athletes compared to female athletes ($p<0.01, ES=1.09–1.52$). For female athletes, no significant changes over time or between groups were reported.

Figure 6.5. Significant differences in (a) hip flexion angle, (b) hip flexion RoM, (c) vGRF and (d) ankle dorsiflexion moment; results of 3-way repeated measures ANOVAs.

Abbreviations: ANOVA = analysis of variance; RoM = range of motion; vGRF = vertical ground reaction force.
* indicates significant difference in VI males between pre- and posttest
† indicates significant difference at posttest between VI males and CTRL males
‡ indicates significant difference between males and females.
DISCUSSION

This study examined the effect of video feedback using overlay on DVJ landing technique in male and female team sport athletes. The primary finding was that males in the VI group had increased hip flexion angle and RoM at peak knee valgus or varus moment, while ankle dorsiflexion moment and vGRF at peak knee valgus or varus moment decreased when compared to the CTRL group. Knee valgus moment, knee flexion angle and RoM did not change as a result of the feedback. In addition, at posttest, a lower vGRF and ankle dorsiflexion moment was found for the males in the VI group compared to the males in the CTRL group. This change in landing technique in males in the VI group was supported by an improved expert and athlete overlap. Although for females in the VI group the percentage overlap increased during the sessions, no significant change in landing kinematics or kinetics was found.

As a potential explanation for our results, observation of the video feedback may have stimulated imitation of the observed jump-landings by triggering the mirror neuron system. When an athlete is presented with a motor action that shares characteristics with a similar motor action that is already in the athlete’s motor repertoire, the athlete will be inclined to repeat it; this may increase the learning effect.43,44 That was the motivation in this study to match expert and athlete based on height and sex.

The findings for the male athletes partly supported our hypothesis; using video feedback with overlay method in male athletes could favorably change landing technique. To the best of our knowledge, only one of the studies regarding effect of video feedback on two-legged landings has included sex as a between subject factor in the model as in the present study.29 Welling and colleagues reported sex differences in response to external focus feedback on DVJ landing as well. However, their results differed from the results in this paper. Males did not change landing technique after external focus instructions, while females did change landing technique.29 Also, in contrast to our study, both male and female athletes showed improved landing technique expressed by a lower LESS score after expert-only video feedback.29 These findings combined with differences in ACL injury risk factors between male and female athlete,45 highlight the need for the development of sex specific ACL injury prevention programs.

Similar to our study, two studies measured the effect of video feedback on vGRF during a double legged jump-landing task, but included male and female recreational athletes in one analysis.26,27 Nevertheless, in contrast to our results, a reduction of vGRF was previously found for control and intervention groups,26 whereas a separate study found that vGRF reduced, but the decrease did not reach...
significance. The changes in landing technique in the present study showed a softer landing pattern. Whether this softer landing pattern also indicates a lower ACL injury risk for males is unclear, since literature on biomechanical risk factors during landing in males is scarce. However, potentially a stiff landing may increase load on the ACL in males and therefore may increase ACL injury risk. Determining what characterizes an ACL injury risk free jump-landing pattern in males should be topic of further research.

Contrary to our hypothesis, this study did not find effects of video feedback on knee kinematics and kinetics (i.e., knee valgus moment, knee flexion moment, knee flexion angle and knee RoM). In other video feedback studies, increases in knee flexion angles and RoM were reported during a box-drop-jump, spike jumps or jump-landing tasks. These studies used self-feedback or a combination of expert and self-feedback, in some cases combined with verbal instructions and a checklist. Additionally, an intervention combining strength training with video feedback resulted in a decreased knee valgus moment in female athletes. The lack of (significant) changes in knee kinematics and kinetics may be attributed to the type of feedback provided. Previous research combined video feedback with other modes (e.g., verbal instructions, strength training, etc.). Those factors may have contributed to greater positive changes that were not observed in the current study. Potentially, adding external focus verbal instructions that have shown to be effective in increasing knee flexion/RoM, such as “land softly”, could have been useful for the athletes to better reproduce the required motion. It is also plausible that athletes focused on the largest differences between expert and athlete contours, for instance hip flexion and overall bending of the body. The differences in knee valgus or knee flexion in the overlap view may not have been that obvious.

Previous studies have reported immediate positive effects of video feedback on landing technique. Interestingly, two short training sessions of 15 minutes within two weeks were sufficient to change landing technique for male athletes. A note of caution is needed here since no changes in frontal and sagittal plane knee kinematics and kinetics were found as a result of the feedback. This may indicate that little time investment is needed from medical and training staff. In terms of clinical relevance, a recent study showed that a similar type of video feedback (expert contours only) improved landing technique while performance on a jump was not compromised. The short-term results found in the current study may provide some preliminary evidence that the learning process continues after the training sessions even when no feedback was provided, the brain is still processing the observed and executed landings, a process also called ‘motor imagery’. However, the long-term effects of
the feedback method with overlay method on landing technique and performance and how these effects influence ACL injury risk need to be analyzed before recommendations can be given to training staff and coaches.

For males, increased expert and athlete overlap during TR1 and TR2 was maintained during posttest expressed by improved landing technique. By imitating an expert performer, and therefore increasing the amount of overlap, males were able to change their landing pattern. This link was expected for males and females, since the athlete’s accelerations and decelerations during the jump-landing play an important role in the calculation of both outcome measures (i.e. landing technique and percentage overlap), in other words, timing connects them. Since percentage overlap and landing technique were not collected at the same time and percentage overlap is just one value for the whole DVJ, no conclusions can be drawn regarding which body parts contributed the most to the increased overlap for males in the VI group. However, future developments of the VizMo tool may allow this. Nevertheless, the measured landing strategies at posttest suggest that the movement of hip and ankle joints contributed the most. In contrast, the link was not found for females. Female athletes in the VI group enhanced percentage overlap, but their landing technique did not change from pre- to posttest in the feedback group. Overall females started at a higher percentage overlap (82.66 ± 3.95%) at the start of TR1 compared to males (80.68 ± 3.62%) (p=0.05). The males presented a slightly (non-significant) larger increase in percentage overlap than females during TR1. It seemed that females were able to increase the percentage overlap with the expert performer to some extent, however this was not sufficient to change landing technique. Given that VizMo offers a 2D moving image, some aspects of the 3D motion are less well presented and are implicitly inferred by the subject. Potentially, the 2D moving image is sufficient for males, while females need to see a video in 3D (or see it from different sides) to be able to translate it to their 3D landing biomechanics.

The lack of effect of video feedback on landing technique for females can be expected retrospectively based on previous literature as our study did not provide additional information concurrently with the video feedback. As described above, studies that included additional components were effective in changing landing technique.\textsuperscript{26,28,46} For instance, video feedback combined with a checklist with information on correct landing technique was presented to athletes resulted in increased hip flexion angle and ankle dorsiflexion angle on a spike jump in female volleyball athletes.\textsuperscript{28} Moreover, the athletes were allowed to ask for further information if instructions were unclear.\textsuperscript{28} Potentially, this additional information could be a first explanation of why the female athletes in the study of Parsons and Alexander\textsuperscript{28} demonstrated
a change in landing technique, and why the female athletes in the present study did not. In another study of our research group females did not change their landing pattern during a side-step task after video feedback, whereas verbal feedback seemed to change landing technique.\textsuperscript{41} Further research is necessary to gain insight in to how video feedback should be combined with verbal instructions for female athletes. A second potential explanation is that females may lack muscle strength and control, which is necessary to perform the desired jump-landing strategy.\textsuperscript{7,45} For instance, females may show decreased hamstring strength compared to quadriceps strength, resulting in an unbalanced hamstring to quadriceps ratio.\textsuperscript{7,45} This may restrict the skills in the athlete’s motor repertoire, which can result in a smaller degree of response in the brain when seeing the action.\textsuperscript{47} Therefore, female athletes may need more input to benefit from the video feedback with overlap method and learn a landing pattern characterized by lower injury risk. A last explanation may be that males usually are better in spatial tasks, whereas females favor other tasks such as verbal memory tasks.\textsuperscript{48}

Some limitations of this study should be mentioned. First, the reliability and accuracy of skin-based markers during dynamic tasks in estimating knee joint kinematics may be limited.\textsuperscript{49,50} The expert reference values were mostly based on female ACL injury risk factors, since literature regarding ACL injury risk factors for male athletes is scarce.\textsuperscript{11,12} Therefore, further research is warranted to determine which neuromuscular and biomechanical factors place male athletes at higher risk to sustain an ACL injury. In addition, in the present study, the frequency of feedback was fixed in order to allow comparison between groups. By using this semi self-controlled feedback strategy, we tried to increase motivation of athletes to perform the task. However, motivation could even have been greater if athletes are allowed to choose their own feedback frequency.\textsuperscript{51} Even though we tried to account for differences in body size by matching height and sex and by including a homogeneous athletic population, the body size still may have influenced the percentage overlap. Ways to account for differences in body size need to be evaluated. Furthermore, although expert and athlete were matched based on sex and height, each athlete may have his or her own optimal movement pattern based on unique characteristics of each individual (i.e. body size estimates, limb length). This was stimulated by letting the athletes discover by themselves how they wanted to imitate the expert. However, the potential of using a self-expert in this new type of video feedback would be an interesting topic for future studies.

The task instructions for the video and verbal group might have directed attention internally to some extent. Focus on the whole movement might direct attention
on the body, however it does not direct attention to a specific body part. Nevertheless, we cannot be sure what the athlete exactly thinks and how this information is processed. Moreover, the addition of verbal (internal) instructions to video feedback may even be beneficial for processing information.\textsuperscript{28} Finally, although a link was found between landing technique and percentage overlap of expert and athlete during a landing, the reliability and validity of the VizMo tool are yet unknown and will be examined in further research.

In conclusion, by providing video feedback with the overlay method male athletes can improve DVJ landing technique. During training sessions, the males in the VI group increased percentage overlap with the expert performer. Females may need additional (verbal) feedback to benefit from the video feedback as well. Comparison of a video and verbal feedback group with a control group and a group receiving internal focus instructions and combinations of these feedback groups (e.g. video combined with internally focused instructions or externally focused instructions) is recommended. In future investigations, it might be possible to combine frontal and sagittal plane feedback as well.

This study adds to the growing body of evidence showing that video feedback is an assistive tool to train safe movement patterns. Novel external feedback techniques for ACL injury prevention continue to be developed and have reported promising results.\textsuperscript{30}

**ACKNOWLEDGEMENTS**

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REFERENCES


## Appendix.

### Results of repeated measures ANOVAs for the drop vertical jump

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<th>Variable</th>
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<th>Time x Group</th>
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<td>M</td>
<td>-0.06 ± 0.28</td>
<td>-0.03 ± 0.32</td>
<td>-0.17; 0.11</td>
<td>-0.01 ± 0.22</td>
<td>0.12</td>
<td>0.10</td>
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<tr>
<td>Knee flexion moment (N(\cdot)m(\cdot)kg(^{-1}))</td>
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<tr>
<td>F</td>
<td>-1.71 ± 0.38</td>
<td>-1.65 ± 0.46</td>
<td>-1.94; -1.36</td>
<td>-1.81 ± 0.49</td>
<td>2.11</td>
<td>0.17</td>
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<tr>
<td>M</td>
<td>-2.03 ± 0.72</td>
<td>-2.13 ± 0.62</td>
<td>-2.43; -1.83</td>
<td>-1.93 ± 0.66</td>
<td>-2.23</td>
<td>-1.63</td>
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<tr>
<td>Ankle dorsiflexion moment (N(\cdot)m(\cdot)kg(^{-1}))</td>
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</tr>
<tr>
<td>F</td>
<td>1.13 ± 0.45</td>
<td>1.09 ± 0.36</td>
<td>1.48; 2.00</td>
<td>1.09 ± 0.46</td>
<td>0.84</td>
<td>1.64</td>
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<tr>
<td>M</td>
<td>1.74 ± 0.55</td>
<td>1.87 ± 0.62</td>
<td>1.60; 2.14</td>
<td>1.88 ± 0.59</td>
<td>0.84</td>
<td>1.03</td>
</tr>
<tr>
<td>vGRF (N(\cdot)kg(^{-1}))</td>
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<tr>
<td>F</td>
<td>11.84 ± 2.45</td>
<td>11.44 ± 2.73</td>
<td>9.91; 12.96</td>
<td>11.84 ± 2.76</td>
<td>10.41</td>
<td>9.53</td>
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<tr>
<td>M</td>
<td>15.76 ± 2.52</td>
<td>16.57 ± 3.93</td>
<td>15.00; 18.15</td>
<td>15.97 ± 3.19</td>
<td>14.55</td>
<td>12.33</td>
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<tr>
<td>Hip flexion angle (°)</td>
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<tr>
<td>F</td>
<td>52.78 ± 11.48</td>
<td>52.16 ± 13.22</td>
<td>46.44; 59.11</td>
<td>51.66 ± 13.95</td>
<td>44.39</td>
<td>34.97</td>
</tr>
<tr>
<td>M</td>
<td>58.00 ± 13.53</td>
<td>49.84 ± 10.27</td>
<td>43.29; 56.39</td>
<td>52.90 ± 14.67</td>
<td>45.62</td>
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<td>Knee flexion angle (°)</td>
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<tr>
<td>F</td>
<td>-78.24 ± 6.25</td>
<td>-76.97 ± 8.13</td>
<td>-81.13; -72.82</td>
<td>-75.68 ± 9.12</td>
<td>-80.74</td>
<td>-82.49</td>
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<tr>
<td>M</td>
<td>-78.47 ± 7.41</td>
<td>-74.34 ± 7.22</td>
<td>-78.65; -70.04</td>
<td>-77.80 ± 8.22</td>
<td>-82.86</td>
<td>-85.77</td>
</tr>
</tbody>
</table>

Innovative video feedback on jump landing improves landing technique in males.
Appendix. Continued.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pretest</th>
<th>Posttest</th>
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<tbody>
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<td></td>
<td>CTRL</td>
<td>VI</td>
</tr>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
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<tr>
<td>Ankle dorsiflexion</td>
<td>8.44;</td>
<td>7.30;</td>
</tr>
<tr>
<td>angle (°)</td>
<td>9.34;</td>
<td>7.57;</td>
</tr>
<tr>
<td>Hip flexion range</td>
<td>29.72; ± 12.41</td>
<td>35.40; ± 12.23</td>
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<tr>
<td>(°)</td>
<td>26.96; ± 10.79</td>
<td>32.64; ± 23.23</td>
</tr>
<tr>
<td>Knee flexion range</td>
<td>-55.49; ± 8.18</td>
<td>-51.57; ± 54.83; ± 9.09</td>
</tr>
<tr>
<td>(°)</td>
<td>-52.45; ± 6.54</td>
<td>-48.53; ± 52.02; ± 5.97</td>
</tr>
<tr>
<td>Ankle flexion range</td>
<td>3.17; ± 9.75</td>
<td>36.09</td>
</tr>
</tbody>
</table>

Abbreviations: CTRL = control group; VI = video feedback group; F = female; M = male; CI = confidence interval; * = significant difference
Innovative video feedback on jump landing improves landing technique in males.
Injury Prevention in Team Sport Athletes

Joan Dallinga