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## Motor learning in ACL injury prevention

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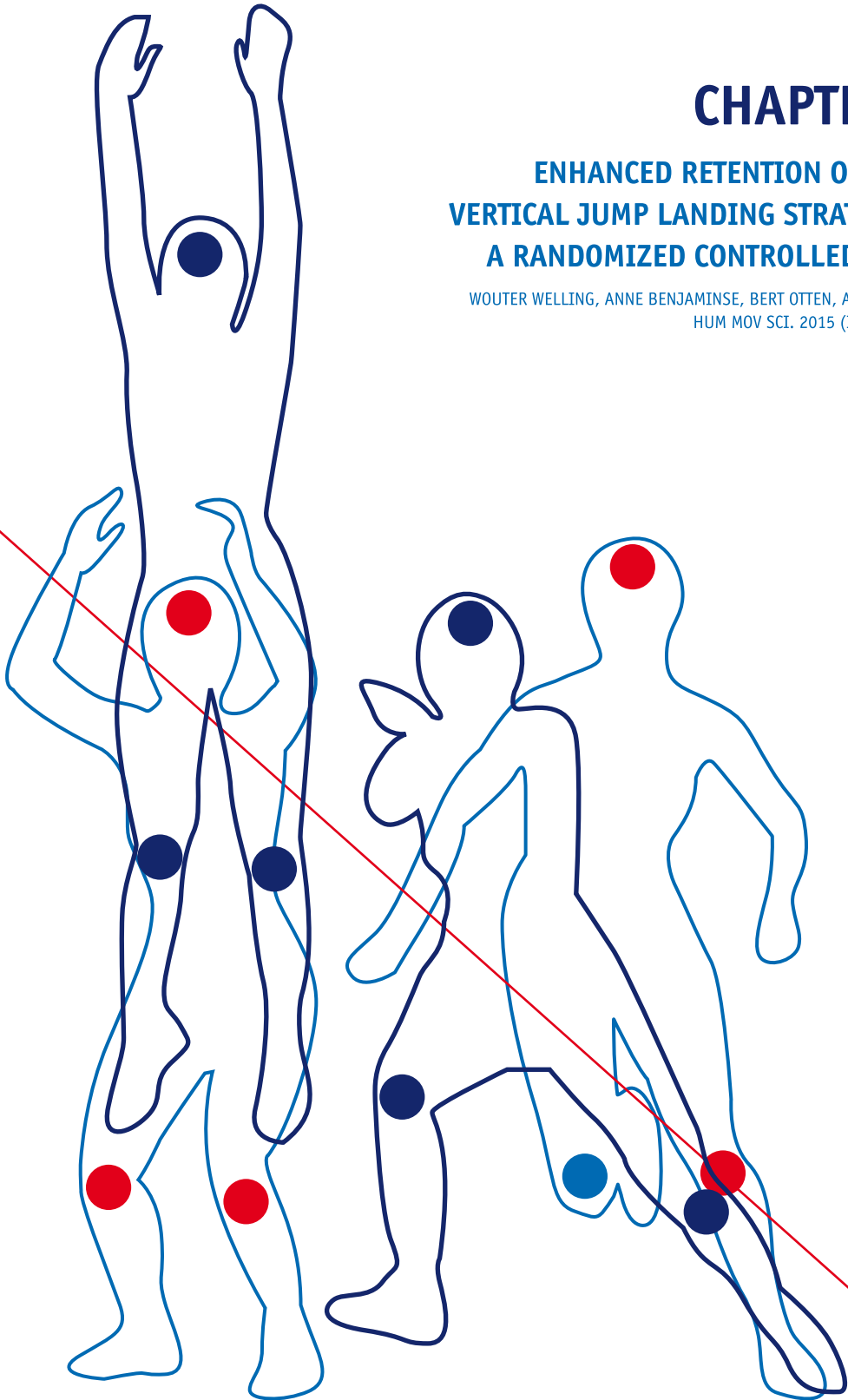
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# CHAPTER 5

## ENHANCED RETENTION OF DROP VERTICAL JUMP LANDING STRATEGIES: A RANDOMIZED CONTROLLED TRIAL

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HUM MOV SCI. 2015 (IN REVISION)



## **Abstract**

External focus instructions have been shown to result in superior motor performance compared to internal focus instructions. Using an EF may help to optimize current anterior cruciate ligament (ACL) injury prevention programs. The purpose of the current study was to investigate the effects of instructions on landing technique and performance by comparing an external focus (EF), internal focus (IF), video (VI) and control (CTRL) group. Subjects (age  $22.50 \pm 1.62$  years, height  $179.70 \pm 10.43$  cm, mass  $73.98 \pm 12.68$  kg) were randomly assigned to IF (n=10), EF (n=10), VI (n=10) or CTRL group (n=10). Subjects performed a drop vertical jump (DVJ) in five sessions: pretest, two training blocks (TR1 and TR2), posttest directly after the training sessions and retention test one week later. Group specific instructions were offered in TR1 and TR2. Landing technique was measured with the Landing Error Scoring System (LESS) and jump height was taken as performance measure. The results show that males in the VI group and females in the VI and EF groups significantly improved jump-landing technique. Retention was achieved and jump height was maintained. It is therefore concluded that EF and VI instructions have great potential in ACL injury prevention.

## Introduction

Anterior cruciate ligament (ACL) injury prevention programs are effective in the short term, but lack effectiveness in the long term.<sup>5</sup> Thus, there is a need for optimization of current ACL injury prevention programs considering the relatively large number of subjects needed to treat<sup>30</sup> and associated time investment of training staff.<sup>32</sup> Most ACL injury prevention programs use verbal instructions directed towards specific knowledge of body movements.<sup>26,38,46</sup> However, a novel approach in ACL injury prevention would be to adopt knowledge of motor learning.<sup>5,19</sup> Motor skills can be learned with attention directed to the movement itself (e.g. “keep your knees over your toes”), which is defined as an internal focus (IF).<sup>54</sup> Whereas with an external focus (EF), attention is directed towards the effect of the movement (e.g. “point your knee toward an imaginary point in front of you”).<sup>54</sup>

Recent studies showed effectiveness of training to optimize a drop vertical jump (DVJ) assessed with the Landing Error Scoring System (LESS).<sup>16,43</sup> The subjects were divided in a short-duration (3 months intervention) and extended-duration (9 months intervention) group and received a set of IF instructions and cues (i.e. “keep your toes pointed straight ahead”, “keep your knees over your toes” and “land softly on your toes while bending your knees”). Although both groups improved their total LESS scores from pretest to posttest, only the extended-duration training group retained their improvements 3 months after ceasing the injury prevention program. Although the LESS improved, these IF instructions likely led to suboptimal motor learning, resulting in relatively less retention and transfer compared to what would have been observed with EF instructions. Paying attention to motor skills can work counterproductive for automatization of movement skills.<sup>4,8,17</sup> The high number of repetitions needed might require too much time commitment, potentially decreasing compliance in coaches and athletes.<sup>18,21,28,32,50</sup> On the other side, adopting EF instructions and feedback might be less attention demanding, improve skill retention and transfer to sport and optimize program efficiency, making the effect of these programs less transient.<sup>7,54</sup> Furthermore, in a recent systematic review it has been shown that an EF enhances motor performance and technique and improves neuromuscular coordination.<sup>8,31,47</sup> For example, greater knee flexion angles,<sup>31</sup> more center of mass (CoM) displacement<sup>53</sup> and lower peak vertical ground reaction forces (vGRF)<sup>33,51</sup> were observed in jump landing activities. These results all suggest to be beneficial in reducing the risk of ACL injury. Hence, adoption of knowledge from the motor learning domain seems promising to enhance ACL injury prevention.<sup>5,8,20</sup> In addition, visual feedback has been shown to be effective.<sup>37,39,40,45</sup> These programs could be expanded to include modern technology such as video with expert learning, self-learning and variations of feedback.<sup>5</sup>

This study was conducted considering the room for improvement in terms of retention of learned motor skills and time investment required from training staff. The primary purpose of the present study was to investigate the effects of instruction on landing technique and performance comparing an EF, IF, video (VI) and a control (CTRL) group. Additionally, it was examined whether possible beneficial results still existed at a retention test one-week after the testing session. The secondary purpose was to measure the consistency by which participants followed the prescribed attentional focus instructions.<sup>48</sup> It was hypothesized that the EF and VI groups would show a better landing technique (i.e. lower LESS score) compared to the IF and CTRL groups, while maintaining performance (i.e. jump height).

## Materials and Methods

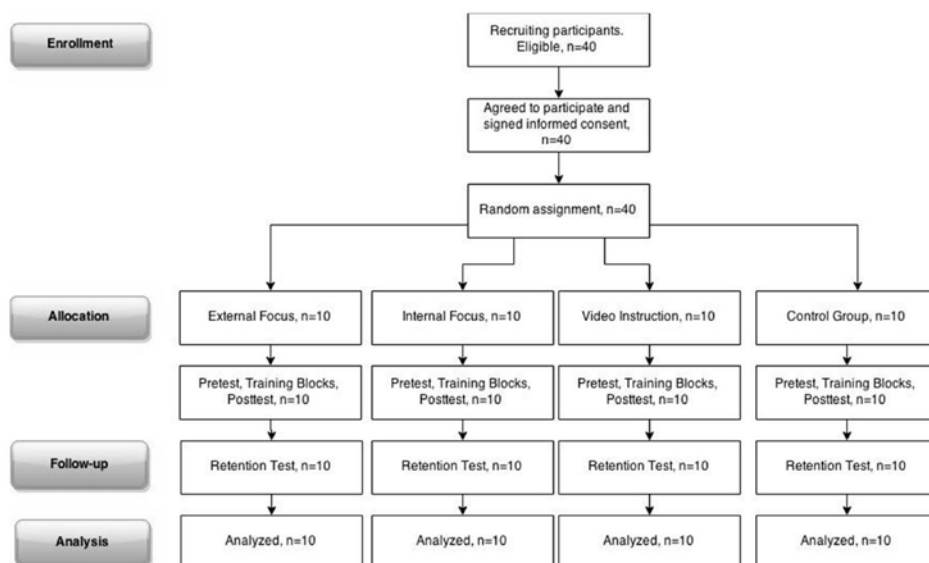
### Subjects

A randomized controlled trial was conducted in a controlled laboratory setting. Forty (twenty males, twenty females) subjects were recruited from local sports clubs (Table 1). For inclusion, subjects had to be: 1)  $\geq 18$  years old and 2) physically active in (recreational) ball team sports for a minimum of four hours per week. Subjects were excluded if they had lower extremity injury in the past 6 months. Enrollment, allocation and testing was conducted by the first author. Subjects were randomly allocated with a MATLAB 6.1 (The MathWorks Inc., Natick, MA) randomization script to one of the four groups based on sex, age and length: IF group with verbal instructions (IF), EF group with verbal instructions (EF), video instructions group (VI) or the control group with no specific instruction (CTRL) (Figure 1). With an effect size of 0.25 (medium effect ANOVA)<sup>13</sup> and an alpha of 0.05, a power of 0.80 was reached with 40 subjects. G\*Power for Windows, Version 3.1.7. has been used to calculate the required sample size.

**Table 1.** Descriptive of subjects per group (mean $\pm$ SD).

	EF	IF	VI	CTRL
N	10	10	10	10
Sex (m/f)	5/5	5/5	5/5	5/5
Age (years)	22.60 $\pm$ 1.35	22.10 $\pm$ 2.64	22.90 $\pm$ 0.57	22.40 $\pm$ 1.35
Height (m)	1.80 $\pm$ 0.14	1.77 $\pm$ 0.08	1.78 $\pm$ 0.10	1.83 $\pm$ 0.11
Mass (kg)	72.40 $\pm$ 10.38	71.10 $\pm$ 6.92	74.40 $\pm$ 17.10	78.00 $\pm$ 14.79

EF = external focus, IF = internal focus, VI = video group, CTRL = control group, m = male, f = female, m = mass, kg = kilogram



**Figure 1.** CONSORT flow chart, including data analysis.

## Procedures

### *Collecting expert data*

Expert videos of drop vertical jumps (DVJ) were created before the start of the current study and made available in the database. The expert videos were selected based on previous research (Table 2).<sup>22,23,36,44</sup> Sex- and size matched expert models were selected for four height ranges (160-170 cm; 170-180 cm; 180-190 cm; 190-200 cm). The expert subjects were ball team sport players as well. Before recording the expert DVJ, general anthropometric measures were taken from the expert subjects. Expert subjects had twenty-one reflective markers of 14 mm in diameter placed according to the Vicon Plug-in-Gait marker set and model. In addition, trunk markers were added to the sternum, clavicle, C7, T10 and right scapula. Vicon's Nexus software (Version 1.6) of the Vicon Motion Analysis System (Vicon Motion Systems, Inc., Centennial, CO) was used to collect and calculate the kinematic and kinetic data for the expert profiles. Ground reaction force (GRF) data was collected using two force plates sampled at 1200 Hz (Bertec Corporation, Columbus, Ohio) and entered in software (Vicon's Nexus software). The force plates were located within a custom-built flooring system in which the force plates are flush with the floor.

**Table 2.** Reference scores expert

Variable	Reference score expert on DVJ
Knee varus/valgus torque (Nm/kg)	<22.25 (female) <sup>36</sup>
Knee flexion range (°)	>45 (male & female) <sup>44</sup>
Peak vGRF (N/kg)	≤59.15 (male) <sup>23</sup> / ≤17.90 (female) <sup>12</sup>

DVJ = drop vertical jump, Nm = Newton meter, kg = kilogram, peak vGRF = peak vertical ground reaction force, N = Newton

### *Collecting subject data*

On day one, before testing, all subjects signed an informed consent form. The study was approved by the medical ethical board of the University of Groningen (ECB/2014.1.20\_1). Subjects were not aware of the specific purpose of the current study. All subjects wore spandex shorts and shirts (for females) and their own athletic shoes during the test session. All subjects performed a 5-minute warm-up on a home trainer at 110 Watt followed by three squats, three lunges per leg and three vertical jumps prior to the test. After completing the warming-up, the subjects received the general instructions and practiced the DVJ. During general task instruction, emphasis was placed on subjects jumping as high as they could immediately after landing from the box.

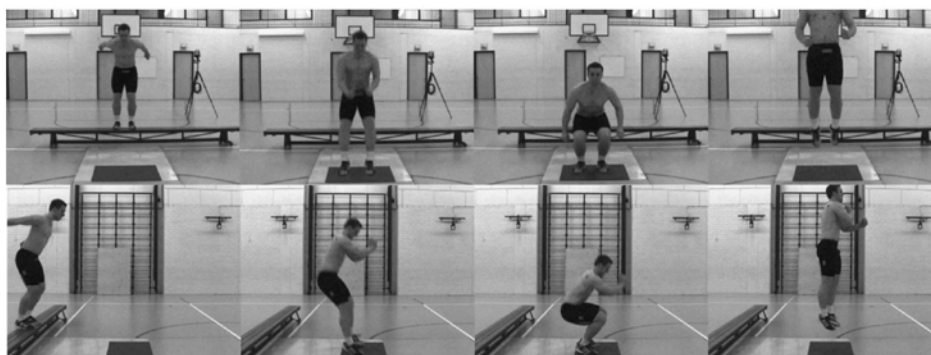
After getting familiar with the task (average three trials), the first five recorded DVJs, served as pretest (baseline measurements). The DVJ protocol was performed according to the protocol by Padua et al.<sup>44</sup> Subjects jumped from a 30-cm high box to a distance of 50% of their height away from the box, down to the two force plates on the ground, and immediately rebounded for a maximal vertical jump on landing (Figure 2). After the pretest, the IF group was instructed to pay attention to the body: "extend your knees as rapidly as possible after the landing on the force plate". Whereas the EF group received an instruction directed to the movement effect: "push yourself as hard as possible off the ground after landing on the force plate".<sup>31</sup> The VI group watched an expert video on a television screen (Table 3 and Figure 3). The instructions for each group were repeated after every five trials. Subjects in the EF, IF and VI groups were free to ask for feedback after every DVJ jump in training block 1 (TR1) and training block 2 (TR2). This feedback consisted of their real time LESS score (range 0-15) of that respective jump.<sup>41</sup> Subjects were not informed on which part of the jump they performed better or worse, but they were aware that a lower LESS score implied a better landing technique. This self-controlled feedback schedule is suggested to positively influence the motor learning process as it is more tailored to the performers' needs and motivation than predetermined feedback schedules.<sup>3,9,10</sup> The CTRL group did not receive any instructions or feedback.

**Table 3.** Training schedule with general and group specific instructions and feedback.

	EF (n=10)	IF (n=10)	VI (n=10)	CTRL (n=10)
General instruction before pretest	This is drop vertical jump and the goal is to jump as high as possible when you have landed off the box.			
Pretest	5 DVJ's	5 DVJ's	5 DVJ's	5 DVJ's
Group specific instruction prior to training	Push yourself as hard as possible off the ground after landing on the force plate.	Extend your knees as rapidly as possible after the landing on the force plate.	You will see a video of an expert jump. This jump is performed as perfect as possible. Try to imitate the jump as good as possible.	N.A.
Training (TR1 & TR2)	2 x 10 DVJ's with self-controlled feedback (LESS score) & group specific instruction after every 5 trials	2 x 10 DVJ's with self-controlled feedback (LESS score) & group specific instruction after every 5 trials	2 x 10 DVJ's with self-controlled feedback (LESS score) & group specific instruction after every 5 trials	2 x 10 DVJ's
Posttest (same day)	5 DVJ's	5 DVJ's	5 DVJ's	5 DVJ's
Retention test (1 week after day 1)	5 DVJ's	5 DVJ's	5 DVJ's	5 DVJ's

EF = external focus, IF = internal focus, VI = video instruction, CTRL = control group, DVJ = drop vertical jump, TR1 = training block 1, TR2 = training block 2

A retention test was performed one week later (day two), to check if the possible difference between groups could be attributed to motor learning principles instead of only motor performance. In the retention test, subjects had to perform the DVJ another five times. Only the general instructions were provided, but no feedback was given. After testing, subjects had to fill in a questionnaire about the focus they experienced during the tests.<sup>48</sup> This questionnaire was completed by the subjects on day one and day two to check the efficiency of the instructions in the present study.

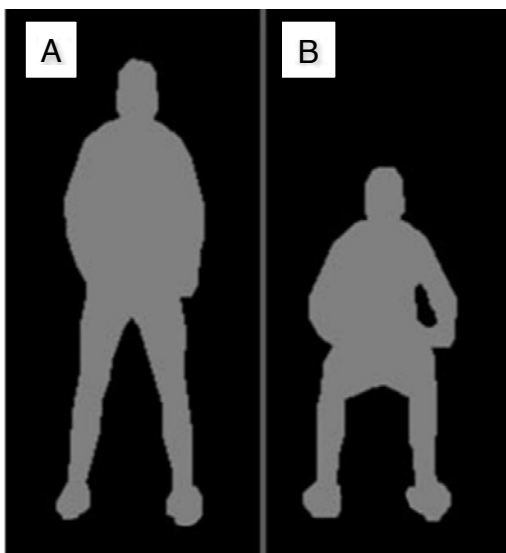


**Figure 2.** The standardized DVJ consists of 2 segments: (1) subject jumps down from box and lands on ground and (2) subject immediately jumps vertically upward as high as possible.



### *Apparatus*

Two Basler cameras (640×480, 210 fps, Vicon Motion Systems, Inc., Centennial, CO) with a 9mm C-mount lens recorded frontal and sagittal plane views of the subject performing the DVJ. Camera and box placement was according to Padua et al.<sup>44</sup> Expert videos were presented on a TV screen (LG, Flatron 65VS10-BAA), driven by a MacBook Pro OS X Version 10.9.5 (Apple inc.).



**Figure 3.** Example of contour of the expert video at initial contact (A) and maximal knee flexion (B) which was shown to the VI group.

### *Data acquisition and statistical analysis*

The frontal and sagittal DVJ videos were imported into video-editing software (Windows Media Player, Microsoft, Redmond, WA). All DVJ videos were independently analyzed and scored (W.W. and A.B.) using the LESS, in which they were blinded to group allocation. Videos were replayed and the DVJ was scored during replay using pause and rewind controls. The rater focused on a designated “test leg”, defined as the dominant leg. We used the question “Which leg do you prefer to kick a ball with?” to establish leg dominance.<sup>44</sup> Scoring was based on the presence or absence of specific landing characteristics. There are 17 scored items in the LESS.<sup>44</sup> Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 20. Primary outcome measures were LESS scores (representing landing technique) and center of mass (CoM) height (representing jump performance) per group and sex and used as dependent variables.

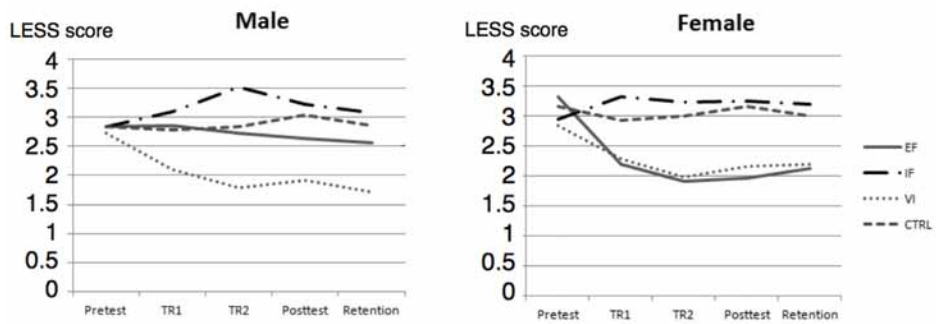
Secondary outcome measures were questionnaire responses that measured the consistency in which subjects followed the prescribed attentional focus instructions. The LESS score represents excellent (LESS score  $<4$ ), good (LESS score  $>4$  to  $\leq 5$ ), moderate (LESS score  $>5$  to  $\leq 6$ ) and poor (LESS score  $>6$ ) jump-landing technique. All data were normally distributed. To determine differences between groups (EF, IF, VI and CTRL), time (pretest, TR1, TR2, posttest and retention test) and sex (female and male), a  $4 \times 5 \times 2$  repeated measures ANOVA was conducted followed by post hoc comparisons (Bonferroni) with alpha level set at  $\alpha \leq 0.05$  a priori. To determine differences in LESS scores and CoM height within groups across time, independent t-tests were conducted. Cohen's effect size (ES) statistics (Cohen's  $d$ ) were calculated to determine the magnitude of observed significant performance differences with  $d=0.2-0.5$ ,  $d=0.5-0.8$  and  $d \geq 0.8$  representing a small, moderate and large effect, respectively.<sup>11</sup> A customized software package using MATLAB 6.1 (The MathWorks Inc., Natick, MA), was used to create a group specific overview in terms of color coded LESS scores written by B.O.

## Results

### Landing technique

Results are presented in Tables 4 and 5 and Figures 4 and 5. No significant differences in baseline LESS scores (pretest) and jump height were found neither between groups nor between male and female subjects. No significant differences were found between groups and sex.

Males in the VI group had significant lower LESS scores in the post test ( $1.92 \pm 0.27$ ) and retention test ( $1.72 \pm 0.30$ ) compared to the pretest ( $2.72 \pm 0.83$ ) ( $p < 0.05$ ). Females in the VI and EF group significantly improved their LESS scores in TR2 (VI:  $1.98 \pm 1.01$ , EF:  $1.90 \pm 0.63$ ), post (VI:  $2.16 \pm 0.95$ , EF:  $1.96 \pm 0.79$ ) and retention test (VI:  $2.20 \pm 0.95$ , EF:  $2.12 \pm 0.78$ ) compared to pretest (VI:  $2.84 \pm 1.03$ , EF:  $3.32 \pm 0.76$ ) ( $p < 0.05$ ).



**Figure 4.** LESS scores separated for male and female subjects.

**Table 4.** LESS scores per sex, group and time (mean  $\pm$  SD).

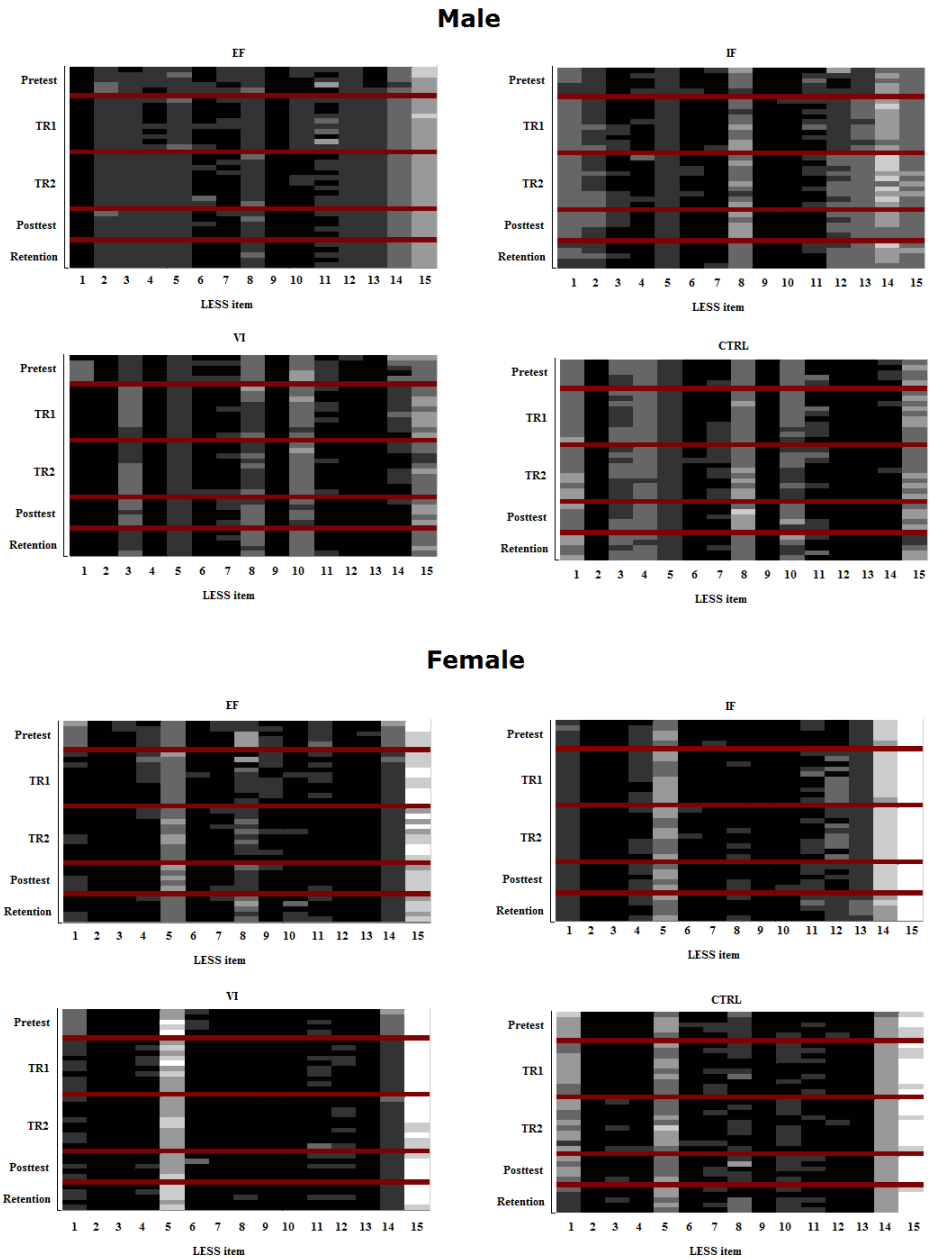
		Pretest	TR1	TR2	Posttest	Retention
Male	EF	2.84 $\pm$ 1.23	2.86 $\pm$ 1.48	2.72 $\pm$ 1.23	2.64 $\pm$ 1.26	2.56 $\pm$ 1.14
	IF	2.84 $\pm$ 1.15	3.10 $\pm$ 1.46	3.52 $\pm$ 1.63	3.22 $\pm$ 1.54	3.08 $\pm$ 1.46
	VI	2.72 $\pm$ 0.83	2.10 $\pm$ 0.44	1.78 $\pm$ 0.58	1.92 $\pm$ 0.27	1.72 $\pm$ 0.30
	CTRL	2.84 $\pm$ 0.90	2.78 $\pm$ 0.91	2.84 $\pm$ 0.71	3.04 $\pm$ 0.92	2.86 $\pm$ 0.59
Female	EF	3.32 $\pm$ 0.76	2.20 $\pm$ 0.80	1.90 $\pm$ 0.63	1.96 $\pm$ 0.79	2.12 $\pm$ 0.78
	IF	2.94 $\pm$ 0.75	3.32 $\pm$ 1.12	3.22 $\pm$ 0.94	3.24 $\pm$ 0.57	3.20 $\pm$ 1.45
	VI	2.84 $\pm$ 1.03	2.28 $\pm$ 0.87	1.98 $\pm$ 1.01	2.16 $\pm$ 0.95	2.20 $\pm$ 0.95
	CTRL	3.16 $\pm$ 0.22	2.92 $\pm$ 0.50	3.00 $\pm$ 0.49	3.16 $\pm$ 0.46	3.00 $\pm$ 0.40

EF = external focus, IF = internal focus, VI = video instruction, CTRL = control group, TR1 = training block 1, TR2 = training block 2. Data are expressed as mean values,  $\pm$  SD.

**Table 5.** P-values of within and between group analysis and effect sizes

	EF			IF			VI			CTRL		
	p-value time	Effect size (95% CI)	p-value time	Effect size (95% CI)	p-value time	Effect size (95% CI)	p-value time	Effect size (95% CI)	p-value time	Effect size (95% CI)		
Male												
Pretest-TR1	N.S.	0.21 (-0.25 to 0.55)	N.S.	0.21 (-0.76 to 0.34)	N.S.	0.98 (0.71 to 1.26)	N.S.	0.07 (-0.31 to 0.45)				
Pretest-TR2	N.S.	0.11 (-0.57 to 0.79)	N.S.	0.54 (-1.32 to 0.24)	N.S.	1.47 (1.07 to 1.87)	N.S.	0.00 (-0.45 to 0.45)				
Pretest-posttest	N.S.	0.18 (-0.51 to 0.87)	N.S.	0.31 (-1.07 to 0.44)	<b>0.047*</b>	1.45 (1.11 to 1.79)	N.S.	0.25 (-0.75 to 0.26)				
Pretest-retention	N.S.	0.26 (-0.39 to 0.92)	N.S.	0.20 (-0.93 to 0.52)	<b>0.020*</b>	1.79 (1.45 to 2.14)	N.S.	0.03 (-0.45 to 0.39)				
TR1-TR2	N.S.	0.11 (-0.46 to 0.67)	N.S.	0.29 (-0.93 to 0.36)	N.S.	0.66 (0.44 to 0.87)	N.S.	0.08 (-0.42 to 0.26)				
TR1-posttest	N.S.	0.18 (-0.58 to 0.94)	N.S.	0.09 (-0.92 to 0.74)	N.S.	0.55 (0.35 to 0.75)	N.S.	0.32 (-0.83 to 0.19)				
TR1-retention	N.S.	0.25 (-0.48 to 0.99)	N.S.	0.02 (-0.79 to 0.83)	N.S.	1.13 (0.92 to 1.34)	N.S.	0.12 (-0.54 to 0.31)				
TR2-posttest	N.S.	0.07 (-0.45 to 0.56)	<b>0.046*</b>	0.20 (-0.46 to 0.86)	N.S.	0.33 (-0.51 to -0.14)	N.S.	0.26 (-0.60 to 0.09)				
TR2-retention	N.S.	0.15 (-0.51 to 0.81)	N.S.	0.32 (-0.54 to 1.18)	N.S.	0.15 (-0.11 to 0.40)	N.S.	0.03 (-0.40 to 0.33)				
Posttest-retention	N.S.	0.07 (-0.43 to 0.57)	N.S.	0.010 (-0.53 to 0.72)	N.S.	0.74 (0.62 to 0.86)	N.S.	0.25 (-0.08 to 0.57)				
Female												
Pretest-TR1	<b>&lt;0.000*</b>	1.51 (1.19 to 1.84)	N.S.	0.42 (-0.82 to -0.02)	N.S.	0.62 (0.22 to 1.02)	N.S.	0.66 (0.49 to 0.82)				
Pretest-TR2	<b>0.001*</b>	2.27 (1.89 to 2.66)	N.S.	0.37 (-0.84 to 0.10)	<b>0.021*</b>	0.94 (0.38 to 1.51)	N.S.	0.47 (0.26 to 0.68)				
Pretest-posttest	<b>0.002*</b>	1.96 (1.53 to 2.39)	N.S.	0.50 (-0.87 to -0.13)	<b>0.026*</b>	0.77 (0.22 to 1.32)	N.S.	0.00 (-0.20 to 0.20)				
Pretest-retention	<b>0.024*</b>	1.74 (1.32 to 2.17)	N.S.	0.25 (-0.89 to 0.39)	<b>0.030*</b>	0.72 (0.17 to 1.27)	N.S.	0.55 (0.38 to 0.73)				
TR1-TR2	N.S.	0.44 (0.14 to 0.74)	N.S.	0.10 (-0.33 to 0.53)	<b>0.034*</b>	0.34 (-0.06 to 0.73)	N.S.	0.17 (-0.38 to 0.04)				
TR1-posttest	N.S.	0.34 (-0.10 to 0.78)	N.S.	0.10 (-0.39 to 0.59)	N.S.	0.15 (-0.36 to 0.65)	N.S.	0.56 (-0.83 to 0.29)				
TR1-retention	N.S.	0.11 (-0.33 to 0.55)	N.S.	0.10 (-0.62 to 0.82)	N.S.	0.10 (-0.41 to 0.60)	N.S.	0.20 (-0.45 to 0.65)				
TR2-posttest	N.S.	0.09 (-0.39 to 0.21)	N.S.	0.03 (-0.35 to 0.30)	N.S.	0.19 (-0.60 to 0.21)	N.S.	0.36 (-0.55 to -0.16)				
TR2-retention	N.S.	0.23 (-0.66 to 0.21)	N.S.	0.04 (-0.57 to 0.65)	N.S.	0.25 (-0.79 to 0.29)	N.S.	0.00 (-0.25 to 0.25)				
Posttest-retention	N.S.	0.22 (-0.54 to 0.11)	N.S.	0.04 (-0.42 to 0.50)	N.S.	0.04 (-0.44 to 0.35)	N.S.	0.39 (0.21 to 0.57)				

EF = external focus, IF = internal focus, VI = video instruction, CTRL = control group, TR1 = training block 1, TR2 = training block 2, N.S. = not significant, CI = confidence interval, \* = significant difference (p≤0.05). Data are expressed as mean values, ± SD.

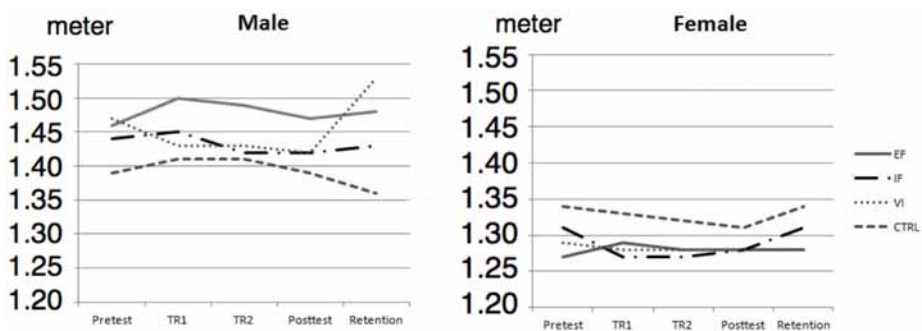


**Figure 5.** Overview of the different scoring pattern in the LESS test for each group on the fifteen LESS items (x-axis) over time points (y-axis) separated for male (left) and female subjects (right). The darker one block is colored, the safer the landing technique.

An overview of the scoring patterns is presented in Figure 5. Each little block in Figure 5 represents a single LESS item over time of all subjects (y-axis). If one little block is colored black it implies that the specific LESS item in that condition was not observed which means, the darker the block, the better. For males, the IF group shows less trunk flexion at maximal knee flexion (item 14) compared to the EF and VI group. Furthermore, the IF and the CTRL group show a more narrow stance width (item 8) compared to males in the EF and the VI group. Additionally, all groups in male subjects show knee valgus at initial contact (IC) (item 5) and knee valgus displacement (item 15) with no improvement over time. Female subjects in the IF group shows less knee flexion at IC (item 1), less maximal knee flexion (item 12) and less trunk flexion at maximal knee flexion (item 14) compared to the EF and the VI group. Furthermore, females in the VI and the EF group showed more knee flexion at IC (item 1) over time. Additionally, female subjects in all groups had knee valgus at initial contact (IC) (item 5) and knee valgus displacement (item 15) with no improvement over time.

### Jump performance

The differences in CoM heights for each group for male and female separated are presented in Figure 6. No significant differences were found between groups and sex. Males in the EF group jumped significantly higher in the TR1 ( $1.50\text{m} \pm 0.03$ ) and TR2 ( $1.49\text{m} \pm 0.04$ ) compared to the posttest ( $1.47\text{m} \pm 0.04$ ) ( $p=0.014$ ;  $p=0.020$ ). Females in the EF group jumped significantly higher in TR1 ( $1.29\text{m} \pm 0.06$ ) compared to posttest ( $1.28\text{m} \pm 0.07$ ) ( $p=0.049$ ).



**Figure 6.** CoM heights separated for male and female subjects.

### Questionnaire responses

Questionnaire responses were organized and coded collectively within each of the conditions into one of three general categories: 'Internal', 'External', or 'Other' for both days (TR1 & TR2 together and retention test). Additionally, the responses were coded into subcategories within each general category (Figure 7).

Males						Females										
IF	Training			Retention			IF	Training			Retention					
Broad Category:	Internal	Other		Internal	Other		Broad Category:	Internal	Other		Internal	Other				
Total responses:	3	2		3	2		Total responses:	4	1		2	3				
Subcategory:	Knees	Mixed		Knees	Mixed	Blank	Subcategory:	Knees	Mixed		Knees	Mixed	Blank			
Responses:	3	2		3	1	1	Responses:	4	1		2	2	1			
<b>EF</b>							<b>EF</b>									
Broad Category:	External	Internal	Other	External	Internal	Other	Broad Category:	External	Other		External	Other				
Total responses:	3	1	1	1	1	3	Total responses:	2	3		1	4				
Subcategory:	Floor	Knees	Mixed	Floor	Knees	Mixed	Subcategory:	Floor	Mixed	Blank	Floor	Mixed	Blank			
Responses:	3	1	1	1	1	3	Responses:	2	2	1	1	3	1			
<b>VI</b>							<b>VI</b>									
Broad Category:	Internal			Internal			Other			Internal			Other			
Total responses:	5			4			1			5			1			
Subcategory:	Knees	Knees & arms		Arms	Feet		Knees	Knees & arms		Mixed		Knees	Feet	Mixed		
Responses:	2	1	1	1	1		3	1	1	1		3	1	1		
<b>CTRL</b>							<b>CTRL</b>									
Broad Category:	External	Internal		Other			Broad Category:	External	Other		External			Other		
Total responses:	1	2		3			Total responses:	1	4		1			4		
Subcategory:	Floor	Knees & arms		Arms	Mixed		Subcategory:	Floor	Mixed		Floor			Mixed		
Responses:	1	1	1	1	3		Responses:	1	4	1			4			

**Figure 7.** Breakdown of questionnaire response categories. Each number represents the total number of questionnaire responses in each of the broad- and subcategories for each experimental condition. The total number of responses in each subcategory equals the number listed in its corresponding broad category. The subcategory of "Mixed" includes responses that included a mixture of internal and external focus.

### Discussion

The purpose of the present study was to investigate the effects of instruction on DVJ landing technique and jump performance, as well as retention after one week. The results show that males in the VI group and females in the EF and VI groups significantly improved their LESS score over time, while maintaining performance. These results indicate successful changes in overall movement quality and lowering chances of potential risk for an ACL injury.<sup>44</sup>

### Landing technique and jump performance

The current findings show that males in the VI and females in the EF and VI groups successfully improved their landing technique (Figure 4), without reducing performance (Figure 6). This is in line with previous studies that used the exact same instructions as used in the present study and were shown to have beneficial results on motor performance (jump distance and jump height) and movement technique (greater knee flexion angle, greater knee range of motion).<sup>20,31</sup> The LESS scores in

our group were all excellent and lower compared to Padua et al.<sup>43</sup> This difference could be attributed to age (youth versus adults) and therefore jumping experience. Even though we examined a “low-risk” population, we were still able to improve technique, perhaps there is even more potential in a “high-risk” population.<sup>35</sup>

Males in the VI group showed greater trunk flexion and stance width compared to the males IF and CTRL groups. Females in the EF and VI group showed greater knee and trunk flexion compared to females in the IF group. Additionally, females in the EF and VI group showed greater knee flexion over time. These findings are in line with previous research showing greater knee flexion when adopting an EF of attention.<sup>12,31</sup> Increased trunk and knee flexion potentially reduce the risk of an ACL injury.<sup>25</sup>

Interestingly, males in the EF group showed no improvement in landing technique, which may imply that sex specific instruction preferences need to be considered when implementing ACL injury prevention programs. This is in line with previous research comparing the response of male and female subjects on focus instructions.<sup>16</sup> In addition, knee valgus motion seems to occur more in female subjects compared to the males (regardless of group) (Figure 5). However, knee valgus motion was also found in male subjects (Figure 5). Perhaps knee valgus is a potential and underexposed ACL injury risk factor in male subjects since there is a lack of research on male ACL injury risk factors.<sup>2</sup> The positive results for the VI and EF groups are best explained by the constrained action hypothesis. That is, when athletes actively focus and consciously control their movements as in the IF group, they disrupt automatic non-conscious motor behavior processes that normally control movements in an efficient manner. In contrast, directing attention to the movement effects, as in the VI and EF groups, allows the motor control system to naturally regulate and organize motor actions.<sup>52</sup>

In the present study, the VI group showed beneficial results for both male and female subjects. Therefore this study is adding to the body of knowledge showing that visual feedback is an efficient tool for improving landing technique.<sup>37,39,40,45</sup> Over the last two decades, promising strategies in neurorehabilitation have been introduced, which are based on the so-called simulation hypothesis.<sup>24</sup> The hypothesis suggests that the neural networks of an action-observation system are activated not only during motor execution but also during observation or imagery of a movement.<sup>29</sup> The mirror neurons facilitate motor learning by automatically mapping observed movements onto a motor program without high cognitive reflections.<sup>49</sup> The contour of the model works like a target for the subject visualizing and replicating the model’s movement as well as possible.<sup>7</sup>



## Retention

The results of the retention test show that the improvements in landing technique and jump performance in males in the VI and in females in the EF and VI group is still present after one week, when no feedback or instructions are given. Interestingly, in the male VI group, there was a trend that males increased performance as jump height was improved from  $1.47\text{m} \pm 0.07$  during pretest to  $1.53\text{m} \pm 0.22$  during retention test. The non-significant change is probably due to a relatively large SD.

However, this is crucial in motor learning as 'learning' a new skill (e.g., movement pattern) should be accompanied by relatively permanent changes.<sup>1,54</sup> Apparently, the learning process initiated with the VI and EF instructions continues by repeating motor patterns in the brain even if no instruction is given (motor imagery).<sup>54</sup> This is a very interesting given as this implicates that automaticity is stimulated resulting in positive retention. This is imperative as only two short training sessions of 15 minutes (TR1 and TR2), was needed to change landing technique, which was maintained a week later. These findings are of high importance as barriers as "it takes too long", "it is boring", "it has no performance benefits" or "it is too difficult"<sup>38</sup> might be countered when implementing EF or VI instructions and feedback that offers self-learning, expert learning and variations of exercises which need only periodic maintenance as a result of sufficient stimuli to learn skills effectively.

## Questionnaire responses

The secondary purpose of the present study was to measure the focus subjects adopted. It is worth noting that during training, the IF males and female subjects reported actually focusing internally in 60% and 80% of the time respectively. This finding is in line with previous research which found 76% of internally focused subjects in the IF group after training.<sup>48</sup> Furthermore, both the VI males and females group experienced an internal focus in 100% in the training and 80% in the retention test. This result is surprising and gives us more insight in the mechanism behind the instructions provided. It is suggested that when subjects watch an expert video, mirror neurons systems are triggered without analyzing the actual movement. After watching the expert video, subjects imitate the expert jump without full awareness on what they are actually doing. Perhaps asking subjects afterwards on what they were focusing, subjects reconstruct the movement by mentally splitting up specific parts that are seen in the video which could lead to an 'error' in their brain. Additionally, males and females in the EF group stated that they focused externally only 60% and 40% of the time in training.

Furthermore, both males and females in the EF group stated that they focused externally only 10% in the retention test. However, the EF females showed positive

results after training and one week later retention. It seems that training subjects with an external focus of attention focused creates a form of learning in which subjects are not fully aware of their learning strategy. This finding is in line with previous research which suggests that when subjects direct their attention externally, the motor control system allows to naturally regulate and organize motor actions.<sup>52</sup>

### **Study limitations and future research**

The LESS is a clinical assessment of movement patterns and we did not measure 3-dimensional lower extremity kinematics and kinetics in this study. Even though the LESS is not a direct measurement of lower extremity biomechanics, it is a valid clinical assessment of movement quality.<sup>44</sup> This is imperative as screening methods that can be completed in a field or clinical setting may be more applicable for wider community use to identify risk factors that may lead to an ACL injury.<sup>42</sup> The advantage of the real time LESS is that it is relatively simple to use and score, making it time and cost effective to implement for coaches in the field. Even though 1-week retention was achieved and other research using the same type of EF and VI instructions shows 4-week retention,<sup>6,15</sup> we cannot generalize the results of the current study to a longer period of time. It is suggested that further research should investigate retention and transfer to the field.<sup>7</sup> In addition landing technique of the non-dominant leg instead of only the dominant leg to study possible asymmetries should be examined. Findings of this study may be limited to this specific population of recreational athletes and may not translate to other populations such as elite or younger athletes. Lastly, more evidence is needed regarding biomechanical risk factors for ACL injury in male athletes.<sup>2</sup>

### **Practical implementation in the field**

This study adds to the current evidence that a verbal EF or video instructions seem to be advantageous compared to an IF induced attention. Recent literature showed that subjects improved landing technique after IF focus instructions, however decreased their jump height.<sup>14,34</sup> In contrast, our subjects receiving EF and VI instructions were able to maintain jump height, while improving landing technique. Retention was achieved and it is therefore advised that training staff uses simple EF verbal and video instructions in their training regimens to improve technique. Athlete performance is crucial for injury prevention as trainers and coaches are more likely to adopt an injury prevention program which is not conflicting with performance.<sup>27</sup> These findings may be critical for improving adoption of ACL injury prevention programs and ensuring that individuals develop permanent changes in movement control. The advantage of verbal instructions is that they do not require

any specialized equipment, making them simple and cost effective to implement. Offering video instruction or feedback with an expert video has been shown to be effective in significant improvement in landing technique and could easily be implemented with off-the-shelf camcorders. Together with the real time LESS this offers optimal opportunities for training staff to screen, evaluate and monitor jump landing technique in their athletes.

## **Conclusion**

This study makes a unique contribution to ACL injury prevention by demonstrating the beneficial results of VI instruction in recreational athletes. Females also benefited from verbal EF instructions. EF and VI instructions led to significant improvement in landing technique after a training and remained present one week later. The fact that retention was achieved after only a short training session has great potential to improve the effectiveness of current ACL injury prevention programs. Training staff is encouraged to provide instructions that induce an EF or video instruction in ACL injury prevention programs. Sex specific learning preferences should also be considered. Future research should determine whether prevention programs that include EF or video instruction in fact reduce the ACL injury incidence.

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