Motor learning in ACL injury prevention

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CHAPTER 5

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

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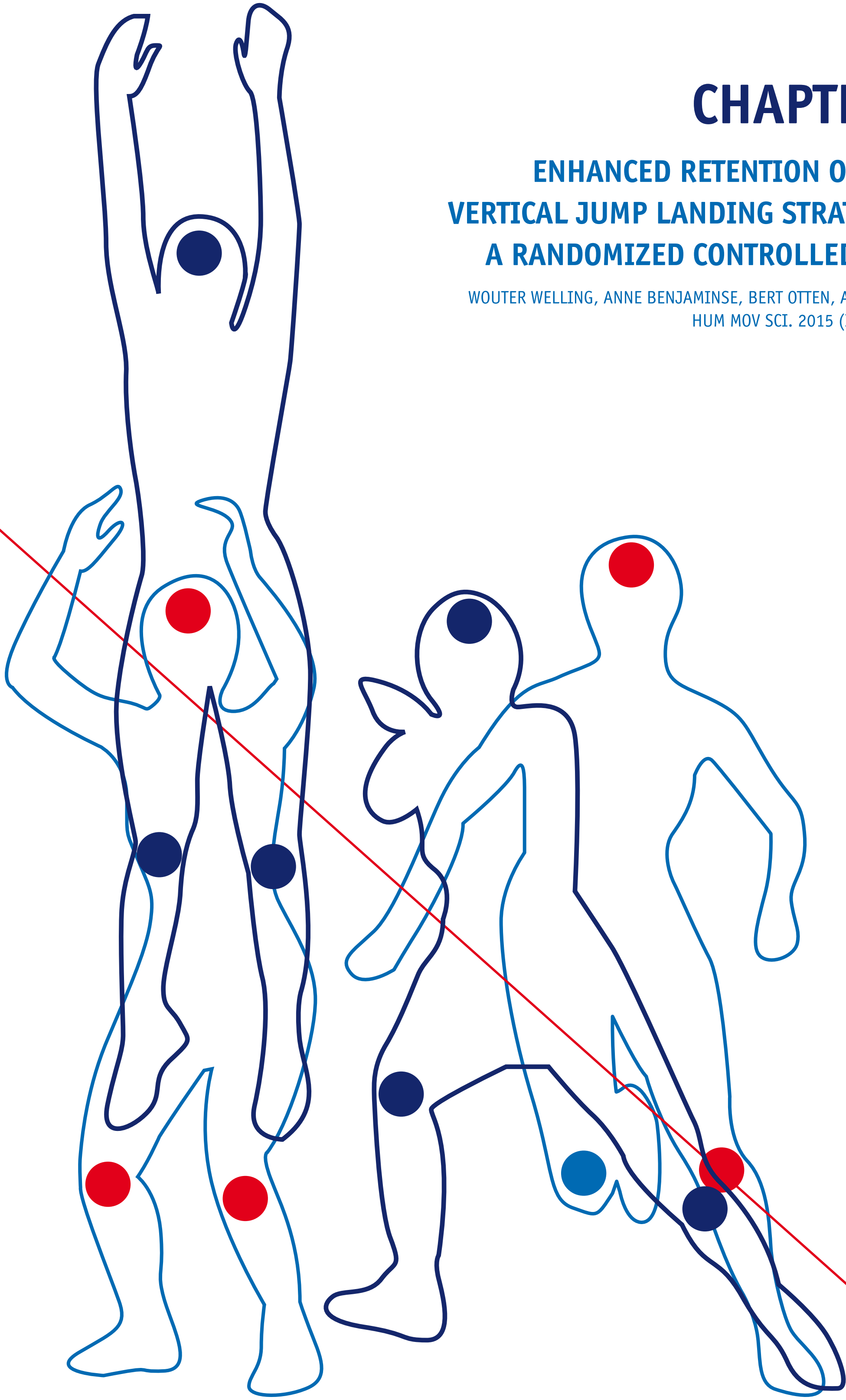
HUM MOV SCI. 2015 (IN REVISION)



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±1.62 years, height 179.70±10.43 cm, mass 73.98±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.[5] Thus, there is a need for optimization of current ACL injury prevention programs considering the relatively large number of subjects needed to treat[30] and associated time investment of training staff.[32] Most ACL injury prevention programs use verbal instructions directed towards specific knowledge of body movements.[26,38,46] However, a novel approach in ACL injury prevention would be to adopt knowledge of motor learning.[5,19] 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).[54] 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").[54]

Recent studies showed effectiveness of training to optimize a drop vertical jump (DVJ) assessed with the Landing Error Scoring System (LESS).[16,43] 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.[4,8,17] The high number of repetitions needed might require too much time commitment, potentially decreasing compliance in coaches and athletes.[18,21,28,32,50] 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.[7,54] Furthermore, in a recent systematic review it has been shown that an EF enhances motor performance and technique and improves neuromuscular coordination.[8,31,47] For example, greater knee flexion angles,[31] more center of mass (CoM) displacement[53] and lower peak vertical ground reaction forces (vGRF)[33,51] 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.[5,8,20] In addition, visual feedback has been shown to be effective.[37,39,40,45] These programs could be expanded to include modern technology such as video with expert learning, self-learning and variations of feedback.[5]

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.[48] 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) ≥ 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)[13] 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±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 ± 1.35	22.10 ± 2.64	22.90 ± 0.57	22.40 ± 1.35
Height (m)	1.80 ± 0.14	1.77 ± 0.08	1.78 ± 0.10	1.83 ± 0.11
Mass (kg)	72.40 ± 10.38	71.10 ± 6.92	74.40 ± 17.10	78.00 ± 14.79

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

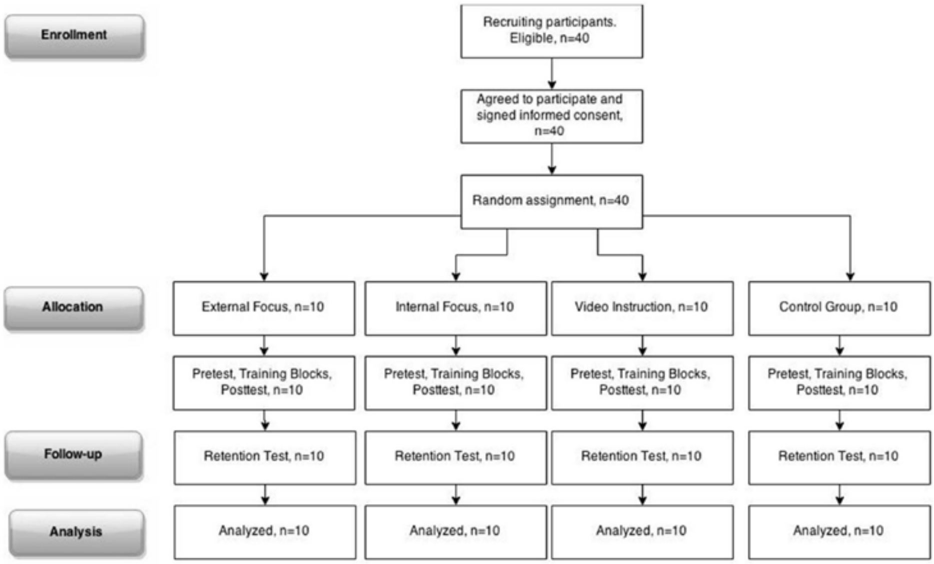


Figure 1. CONSORT flow chart, including data analysis.

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).[22,23,36,44] 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)[36]
Knee flexion range (°)	>45 (male & female)[44]
Peak vGRF (N/kg)	≤59.15 (male)[23] / ≤17.90 (female)[12]

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.[44] 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".[31] 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.[41] 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.[3,9,10] 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

5

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.[48] This questionnaire was completed by the subjects on day one and day two to check the efficiency of the instructions in the present study.

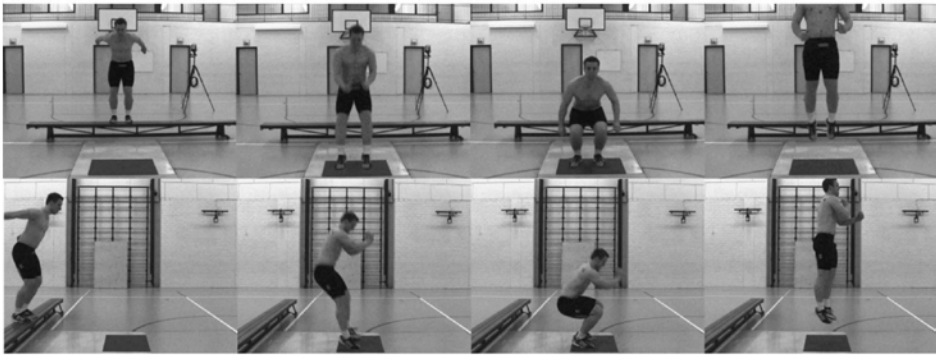


Figure 2. The standardized DJV consists of 2 segments: (1) subject jumps down from box and lands on ground and (2) subject immediately jumps vertically upward as high as possible.

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.[44] 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.).

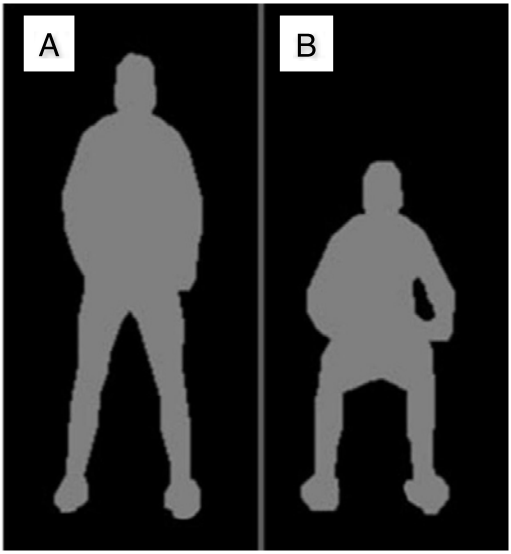


Figure 3. Example of contour of the expert video at initial contact (A) and maximal knee flexion (B) which was shown to the VI group.

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.[44] Scoring was based on the presence or absence of specific landing characteristics. There are 17 scored items in the LESS.[44] 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 ≤5), moderate (LESS score >5 to ≤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 4x5x2 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.[11] 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 ± 0.27) and retention test (1.72 ± 0.30) compared to the pretest (2.72 ± 0.83) ($p<0.05$). Females in the VI and EF group significantly improved their LESS scores in TR2 (VI: 1.98 ± 1.01, EF: 1.90 ± 0.63), post (VI: 2.16 ± 0.95, EF: 1.96 ± 0.79) and retention test (VI: 2.20 ± 0.95, EF: 2.12 ± 0.78) compared to pretest (VI: 2.84 ± 1.03, EF: 3.32 ± 0.76) ($p<0.05$).

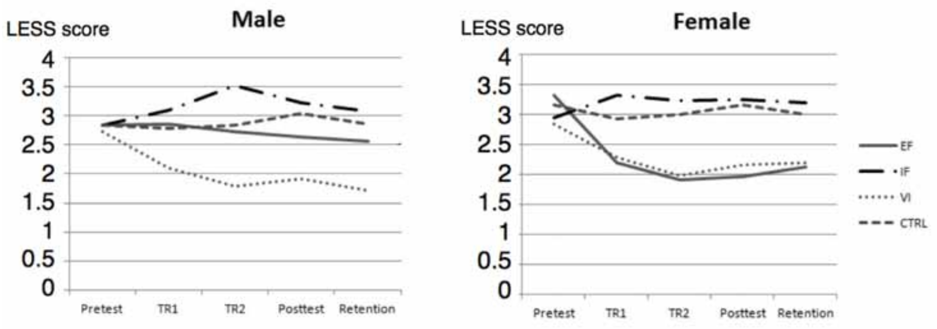


Figure 4. LESS scores separated for male and female subjects.

Table 4. LESS scores per sex, group and time (mean ± SD).

		Pretest	TR1	TR2	Posttest	Retention
Male	EF	2.84 ± 1.23	2.86 ± 1.48	2.72 ± 1.23	2.64 ± 1.26	2.56 ± 1.14
	IF	2.84 ± 1.15	3.10 ± 1.46	3.52 ± 1.63	3.22 ± 1.54	3.08 ± 1.46
	VI	2.72 ± 0.83	2.10 ± 0.44	1.78 ± 0.58	1.92 ± 0.27	1.72 ± 0.30
	CTRL	2.84 ± 0.90	2.78 ± 0.91	2.84 ± 0.71	3.04 ± 0.92	2.86 ± 0.59
Female	EF	3.32 ± 0.76	2.20 ± 0.80	1.90 ± 0.63	1.96 ± 0.79	2.12 ± 0.78
	IF	2.94 ± 0.75	3.32 ± 1.12	3.22 ± 0.94	3.24 ± 0.57	3.20 ± 1.45
	VI	2.84 ± 1.03	2.28 ± 0.87	1.98 ± 1.01	2.16 ± 0.95	2.20 ± 0.95
	CTRL	3.16 ± 0.22	2.92 ± 0.50	3.00 ± 0.49	3.16 ± 0.46	3.00 ± 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, ± 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)
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)	**0.047***	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)	**0.020***	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 067)	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)	**0.046***	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	**<0.000***	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	**0.001***	2.27 (1.89 to 2.66)	N.S.	0.37 (-0.84 to 0.10)	**0.021***	0.94 (0.38 to 1.51)	N.S.	0.47 (0.26 to 0.68)
	Pretest-posttest	**0.002***	1.96 (1.53 to 2.39)	N.S.	0.50 (-0.87 to -0.13)	**0.026***	0.77 (0.22 to 1.32)	N.S.	0.00 (-0.20 to 0.20)
	Pretest-retention	**0.024***	1.74 (1.32 to 2.17)	N.S.	0.25 (-0.89 to 0.39)	**0.030***	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)	**0.034***	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 ($p \le 0.05$). Data are expressed as mean values, ± SD.

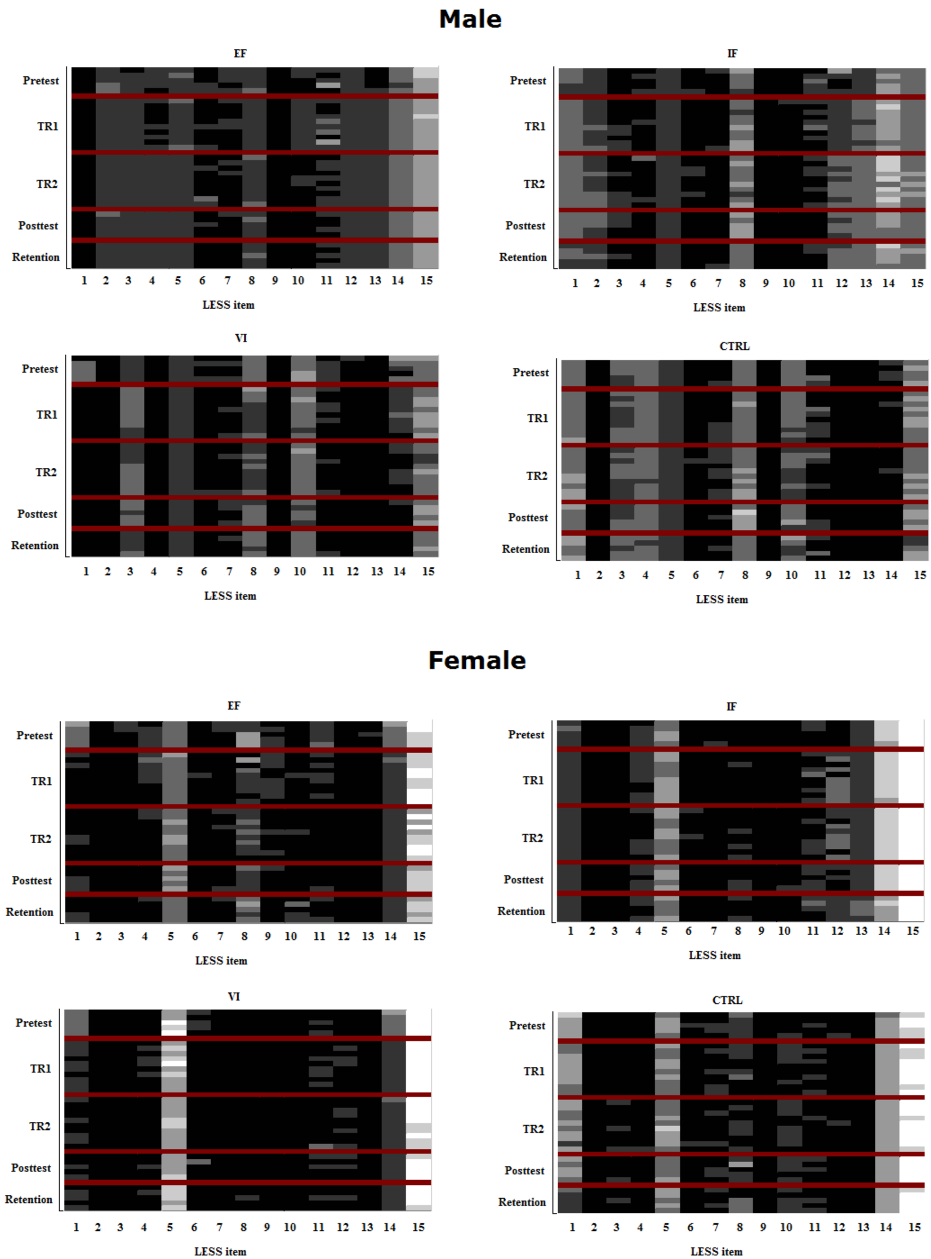


Figure 5. Overview of the different scoring pattern in the LESS test for each group on the fifteen LESS items (x-axis) over time points (y-axis) separated for male (left) and female subjects (right). The darker one block is colored, the safer the landing technique.

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 (1.50m ± 0.03) and TR2 (1.49m ± 0.04) compared to the posttest (1.47m ± 0.04) (p=0.014; p=0.020). Females in the EF group jumped significantly higher in TR1 (1.29m ± 0.06) compared to posttest (1.28m ± 0.07) (p=0.049).

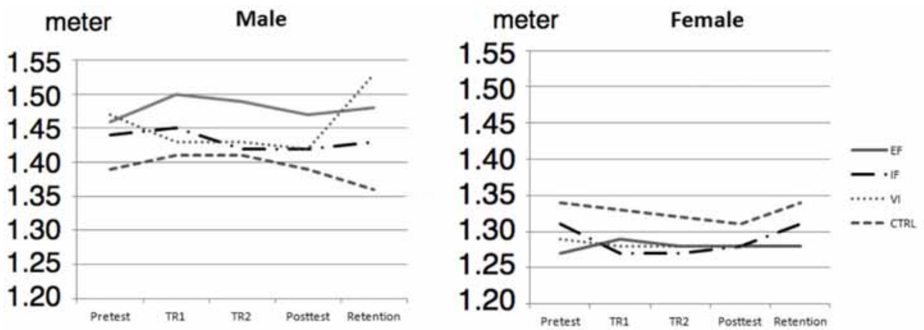


Figure 6. CoM heights separated for male and female subjects.

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

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

Females

IF	Training			Retention		
Broad Category:	Internal	Other		Internal	Other	
Total responses:	4	1		2	3	
Subcategory:	Knees	Mixed		Knees	Mixed	Blank
Responses:	4	1		2	2	1
EF						
Broad Category:	External	Other		External	Other	
Total responses:	2	3		1	4	
Subcategory:	Floor	Mixed	Blank	Floor	Mixed	Blank
Responses:	2	2	1	1	3	1
VI						
Broad Category:	Internal			Internal		Other
Total responses:	5			4		1
Subcategory:	Knees	Knees & arms	Knees & feet	Knees	Feet	Mixed
Responses:	2	2	1	3	1	1
CTRL						
Broad Category:	External	Other		External	Other	
Total responses:	1	4		1	4	
Subcategory:	Floor	Mixed		Floor	Mixed	
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.[44]

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).[20,31] The LESS scores in our group were all excellent and lower compared to Padua et al.[43] 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.[35]

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.[12,31] Increased trunk and knee flexion potentially reduce the risk of an ACL injury.[25]

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.[16] 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.[2] 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.[52]

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.[37,39,40,45] Over the last two decades, promising strategies in neurorehabilitation have been introduced, which are based on the so-called simulation hypothesis.[24] 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.[29] The mirror neurons facilitate motor learning by automatically mapping observed movements onto a motor program without high cognitive reflections.[49] The contour of the model works like a target for the subject visualizing and replicating the model's movement as well as possible.[7]

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 1.47m ± 0.07 during pretest to 1.53m ± 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.[1,54] 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).[54] 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"[38] 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.[48] 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.[52]

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.[44] 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.[42] 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,[6,15] 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.[7] 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.[2]

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.[14,34] 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.[27] 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 benefit-ted 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.

References

1. Adams JA. A closedloop theory of motor learning. J Mot Behav. 1971;3:111–150.
2. Alentorn-Geli E, Mendiguchia J, Samuelsson K, et al. Prevention of anterior cruciate ligament injuries in sports. Part I: systematic review of risk factors in male athletes. Knee Surg Sports Traumatol Arthrosc. 2014;22:3-15.
3. Andrieux M, Danna J, Thon B. Self-control of task difficulty during training enhances motor learning of a complex coincidence-anticipation task. Res Q Exerc Sport. 2012;83:27-35.
4. Beek PJ. Toward a theory of implicit learning in the perceptual-motor domain. Int J Sport Psychol. 2000;31:547–554.
5. Benjaminse A, Gokeler A, Dowling AV, et al. Optimization of the Anterior Cruciate Ligament Injury Prevention Paradigm: Novel Feedback Techniques to Enhance Motor Learning and Reduce Injury Risk. J Orthop Sports Phys Ther. 2015;45:170-182.
6. Benjaminse A, Otten B, Gokeler A, Diercks RL, Lemmink KAPM. Motor Learning Strategies in Basketball Players and its Implications for ACL Injury Prevention: A Randomized Controlled Trial. Knee Surg Sports Traumatol Arthrosc. 2015;Accepted
7. Benjaminse A, Otten E. ACL injury prevention, more effective with a different way of motor learning? Knee Surg Sports Traumatol Arthrosc. 2011;19:622-627.
8. Benjaminse A, Welling W, Otten B, Gokeler A. Novel methods of instruction in ACL injury prevention programs, a systematic review. Phys Ther Sport. 2015;16:176-186.
9. Chiviacowsky S, Wulf G. Self-controlled feedback is effective if it is based on the learner's performance. Res Q Exerc Sport. 2005;76:42-48.
10. Chiviacowsky S, Wulf G, de Medeiros FL, Kaefer A, Wally R. Self-controlled feedback in 10-year-old children: higher feedback frequencies enhance learning. Res Q Exerc Sport. 2008;79:122-127.
11. Cohen J. Statistical power analysis for the behavioral sciences. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.
12. Cowling EJ, Steele JR, McNair PJ. Effect of verbal instructions on muscle activity and risk of injury to the anterior cruciate ligament during landing. Br J Sports Med. 2003;37:126-130.
13. Cunningham JB, McCrum-Gardner E. Power, effect and sample size using GPower: practical issues for researchers and members of research ethics committees. Evid Based Midwifery. 2007;5:132-136.
14. Dai B, Garrett WE, Gross MT, Padua DA, Queen RM, Yu B. The effects of 2 landing techniques on knee kinematics, kinetics, and performance during stop-jump and side-cutting tasks. Am J Sports Med. 2015;43:466-474.
15. Dallinga J, Benjaminse A, Gokeler A, Cortes N, Otten B, Lemmink KAPM. Innovative video feedback on jump landing improves landing technique in males. J Strength Cond Res. 2015;Submitted:
16. DiStefano LJ, Padua DA, DiStefano MJ, Marshall SW. Influence of Age, Sex, Technique, and Exercise Program on Movement Patterns After an Anterior Cruciate Ligament Injury Prevention Program in Youth Soccer Players. Am J Sports Med. 2009;37:495-505.
17. Farrow D, Abernethy B. Can anticipatory skills be learned through implicit video-based perceptual training? J Sport Sci. 2002;20:471-485.
18. Frank BS, Register-Mihalik J, Padua DA. High levels of coach intent to integrate a ACL injury prevention program into training does not translate to effective implementation. J Sci Med Sport. 2014;18:400-406.
19. Gokeler A, Benjaminse A, Hewett TE, et al. Feedback techniques to target functional deficits following anterior cruciate ligament reconstruction: implications for motor control and reduction of second injury risk. Sports Med. 2013;43:1065-1074.

20. Gokeler A, Benjaminse A, Welling W, Alferink M, Eppinga P, Otten B. The effects of attentional focus on jump performance and knee joint kinematics in patients after ACL reconstruction. Phys Ther Sport. 2015;16:114-120.
21. Hagglund M, Atroshi I, Wagner P, Walden M. Superior compliance with a neuromuscular training programme is associated with fewer ACL injuries and fewer acute knee injuries in female adolescent football players: secondary analysis of an RCT. Br J Sports Med. 2013;47:974-979.
22. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. Am J Sports Med. 2005;33:492-501.
23. Hewett TE, Stroupe AL, Nance TA, Noyes FR. Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. Am J Sports Med. 1996;24:765-773.
24. Holper L, Muehlemann T, Scholkmann F, Eng K, Kiper D, Wolf M. Testing the potential of a virtual reality neurorehabilitation system during performance of observation, imagery and imitation of motor actions recorded by wireless functional near-infrared spectroscopy (fNIRS). J Neuroeng Rehabil. 2010;7:
25. Hughes G. A review of recent perspectives on biomechanical risk factors associated with anterior cruciate ligament injury. Res Sports Med. 2014;22:193-212.
26. Irmischer B, Harris C, Pfeiffer R, DeBeliso M, Adams K, Shea K. Effects of a knee ligament injury prevention exercise program on impact forces in women. J Strength Cond Res. 2004;18:703-707.
27. Keats MR, Emery CA, Finch CF. Are we having fun yet? Fostering adherence to injury preventive exercise recommendations in young athletes. Sports Med. 2012;42:175-184.
28. Lindblom H, Waldén M, Carlfjord S, Hägglund M. Implementation of a neuromuscular training programme in female adolescent football: 3-year follow-up study after a randomised controlled trial. Br J Sports Med. 2014;19:1425-1430.
29. Lotze M, Montoya P, Erb M, et al. Activation of cortical and cerebellar motor areas during executed and imagined hand movements: An fMRI study. J Cogn Neurosci. 1999;11:491-501.
30. Lyman S, Koulouvaris P, Sherman S, Do H, Mandl LA, Marx RG. Epidemiology of anterior cruciate ligament reconstruction: trends, readmissions, and subsequent knee surgery. J Bone Joint Surg Am. 2009;91:2321-2328.
31. Makaruk H, Porter JM, Czaplicki A, Sadowski J, Sacewicz T. The role of attentional focus in plyometric training. J Sports Med Phys Fitness. 2012;52:319-327.
32. McGlashan AJ, Finch CF. The extent to which behavioural and social sciences theories and models are used in sport injury prevention research. Sports Med. 2010;40:841-858.
33. McNair PJ, Prapavessis H, Callender K. Decreasing landing forces: effect of instruction. Br J Sports Med. 2000;34:293-296.
34. Munro A, Herrington L. The effect of videotape augmented feedback on drop jump landing strategy: Implications for anterior cruciate ligament and patellofemoral joint injury prevention. Knee. 2014;21:891-895.
35. Myer GD, Ford KR, Brent JL, Hewett TE. Differential neuromuscular training effects on ACL injury risk factors in "high-risk" versus "low-risk" athletes. BMC Musculoskelet Disord. 2007;8:39.
36. Myer GD, Ford KR, Brent JL, Hewett TE. The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes. J Strength Cond Res. 2006;20:345-353.

37. Myer GD, Stroube BW, DiCesare CA, et al. Augmented feedback supports skill transfer and reduces high-risk injury landing mechanics: a double-blind, randomized controlled laboratory study. Am J Sports Med. 2013;41:669-677.
38. Myklebust G, Engebretsen L, Braekken IH, Skjolberg A, Olsen OE, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. Clin J Sport Med. 2003;13:71-78.
39. Onate JA, Guskiewicz KM, Marshall SW, Giuliani C, Yu B, Garrett WE. Instruction of jump-landing technique using videotape feedback: altering lower extremity motion patterns. Am J Sports Med. 2005;33:831-842.
40. Onate JA, Guskiewicz KM, Sullivan RJ. Augmented feedback reduces jump landing forces. J Orthop Sports Phys Ther. 2001;31:511-517.
41. Padua DA, Boling MC, Distefano LJ, Onate JA, Beutler AI, Marshall SW. Reliability of the landing error scoring system-real time, a clinical assessment tool of jump-landing biomechanics. J Sport Rehabil. 2011;20:145-156.
42. Padua DA, DiStefano LJ, Beutler AI, de la Motte SJ, DiStefano MJ, Marshall SW. The Landing Error Scoring System as a Screening Tool for an Anterior Cruciate Ligament Injury-Prevention Program in Elite-Youth Soccer Athletes. J Athl Train. 2015;50:589-595.
43. Padua DA, DiStefano LJ, Marshall SW, Beutler AI, de la Motte SJ, DiStefano MJ. Retention of movement pattern changes after a lower extremity injury prevention program is affected by program duration. Am J Sports Med. 2012;40:300-306.
44. Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett WE, Beutler AI. The Landing Error Scoring System (LESS) Is a Valid and Reliable Clinical Assessment Tool of Jump-Landing Biomechanics The JUMP-ACL Study. Am J Sports Med. 2009;37:1996-2002.
45. Parsons JL, Alexander MJ. Modifying spike jump landing biomechanics in female adolescent volleyball athletes using video and verbal feedback. J Strength Cond Res. 2012;26:1076-1084.
46. Pfeiffer RP, Shea KG, Roberts D, Grandstrand S, Bond L. Lack of effect of a knee ligament injury prevention program on the incidence of noncontact anterior cruciate ligament injury. J Bone Joint Surg Am. 2006;88:1769-1774.
47. Porter JM, Anton PM, Wikoff NM, Ostrowski JB. Instructing skilled athletes to focus their attention externally at greater distances enhances jumping performance. J Strength Cond Res. 2013;27:2073-2078.
48. Porter JM, Nolan RP, Ostrowski EJ, Wulf G. Directing attention externally enhances agility performance: a qualitative and quantitative analysis of the efficacy of using verbal instructions to focus attention. Front Psychol. 2010;1:216.
49. Rizzolatti G. The mirror neuron system and its function in humans. Anat Embryol (Berl). 2005;210:419-421.
50. Sugimoto D, Myer GD, McKeon JM, Hewett TE. Evaluation of the effectiveness of neuromuscular training to reduce anterior cruciate ligament injury in female athletes: a critical review of relative risk reduction and numbers-needed-to-treat analyses. Br J Sports Med. 2012;46:979-988.
51. Wu WF, Porter JM, Brown LE. Effect of attentional focus strategies on peak force and performance in the standing long jump. J Strength Cond Res. 2012;26:1226-1231.
52. Wulf G. Attention and motor skill learning. Champaign, IL: Human Kinetics; 2007.
53. Wulf G, Dufek JS, Lozano L, Pettigrew C. Increased jump height and reduced EMG activity with an external focus. Hum Mov Sci. 2010;29:440-448.
54. Wulf G, Shea C, Lewthwaite R. Motor skill learning and performance: a review of influential factors. Med Educ. 2010;44:75-84.