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The effects of action observation in the lower limb landing biomechanics: a systematic review and meta-analysis

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A – Research concept and design
B – Collection and/or assembly of data
C – Data analysis and interpretation
D – Writing the article
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Abstract

Non-contact ACL injuries usually occur when an athlete lands from a jump. Therefore, landing training is frequently used as an injury-prevention strategy. This systematic review aims to investigate the effects of action observation in the motor learning of the proper landing technique for healthy adults.

Randomized controlled trials were deemed eligible if they included athletically active healthy adults without a history of lower limb injuries and if they compared action observation, in the form of direct observation or video feedback, to the control. The outcome measures were lower extremity biomechanical parameters: sagittal plane flexion angles, dynamic knee valgus and vertical ground reaction force.

Six trials were included. Two trials were rated at low risk of bias, one trial with some concerns and three trials with a high risk of bias. Pooled data analysis indicated that action observation improves peak knee flexion (MD 15.95, 95% CI 3.53 to 28.38, I2 = 92%) and initial contact knee flexion (MD 4.05, 95% CI 1.62 to 6.48, I2 = 0%). It may also improve peak hip flexion (MD 18.16, 95% CI – 1.71 to 38.03, I2 = 92%) and dynamic knee valgus (SMD 0.52, 95% CI – 0.31 to 1.34, I2 = 75%) and has no effect on vertical ground reaction force (SMD – 0.04, 95% CI – 0.68 to 0.61, I2 = 62%) compared to the control.

In conclusion, we can state that action observation is a potential strategy to enhance motor learning of the proper landing technique in healthy individuals.

Keywords: anterior cruciate ligament injuries, biomechanical phenomena, feedback, motor skills, risk factors

Introduction

Anterior cruciate ligament (ACL) injuries are one of the most common sport-related injuries with an estimated average incidence of 1 in 3500 across the athlete population [1]. The consequences of an ACL injury are seen in severe limitations of daily life activities and sports participation [2].

An ACL injury can be caused both by contact (when a direct contusion occurs to the player) and non-contact mechanisms (when there is no physical contact with an object or person). The latter have been shown to be the most common injury mechanism, in particular, when landing from a jump; thus, poor lower limb biomechanics during jump-landing tasks is considered a potential predictor of ACL injury [3,4]. Furthermore, some specific biomechanical parameters of landing tasks are associated with an increased risk of ACL ruptures: reduced knee flexion angle, increased impact ground reaction force (GRF) and dynamic knee valgus (DKV) [5,6]. These biomechanical parameters together cause a "stiff" landing with higher forces on the joints and, consequently, increases the overall load on the lower limbs during the landing phase of a jump-landing task (Fig. 1). The previous literature suggests that it is possible to control these risk factors by improving landing movement patterns and, for this reason, ACL injury prevention programs implement motor learning principles to enhance the acquisition of a better landing technique [7]. These principles include feedback, the learner's focus of attention, self-controlled practice and action observation [8]. Although several studies have demonstrated the effectiveness of the first three strategies in improving the acquisition and reinforcement of motor skills [9–11], evidence on the effectiveness of action observation is still emerging.

Action observation consists in observing a task done by another subject and then practicing that specific movement by trying to imitate the model that has been observed with the purpose of improving your own technique. Neurophysiological studies have described the underlying mechanisms of action observation, which are rooted in activating the mirror-neural system (MNS), a group of neurons that facilitate observational learning and imitation. The MNS is a subset of a more complex neural system called the action observation network (AON), which includes the ventral and dorsal premotor cortex (PMv, PMd), inferior parietal lobule (IPL), superior parietal lobule (SPL), superior temporal sulcus (STS) and dorsolateral prefrontal cortex (DLPFC). The PMv, IPL and STS are part of the subset identified as the MNS [12]. Some researchers found that cortical brain areas that usually activate during a motor task are also activated during the mere observation of that specific task [13,14] and the activation of the AON seems to facilitate the observer's motor system [15]. Findings from several studies suggest that action observation can play an important role in the recovery of motor function in patients with stroke [16–19] and Parkinson disease [20,21], and some authors state that adding action observation to physical practice gives some benefits in learning a new motor skill [22,23]. Nonetheless, little is known about its application in orthopaedics and musculoskeletal conditions. Preliminary studies reported positive results on the effects of action observation in the motor recovery of patients undergoing lower limb arthroplasty surgery [24-26].

Considering that changing brain behaviour using motor learning principles seems to be the main way to enhance the effectiveness of ACL injury prevention programs [27], the emerging evidence about the effects of action observation on motor learning suggests that it could play a significant role in the prevention of ACL injuries. Therefore, this systematic review aims to investigate whether action observation is an effective way to reduce ACL injury biomechanical risk factors of landing tasks in healthy adults and, consequently, to obtain preliminary information about its possible application in injury prevention programs.

Materials and methods

The protocol of this systematic review was registered a priori in PROSPERO (CRD42022332726) and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [28].

Identification and selection of studies

A comprehensive search of five electronic databases – Medline (PubMed), Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, Scopus and Physiotherapy Evidence Database (PEDro) – was conducted from the inception of indexing up until 1st June 2022. Medical Subject Headings and keywords related to the main topics of the review (Action observation, landing task, biomechanics, lower limb) were combined to create the search strategy (Appendix 1 for the detailed search strategy). In addition, Clinicaltrials.gov was searched for ongoing registered trials, which was followed by manual screening of reference sections of all retrieved full-text articles and a grey literature search.

The study selection process followed three main stages: duplicate removal, title and abstract examination and the subsequent removal of obviously irrelevant reports, and then an examination of full-text reports for final inclusion. The process was performed by two independent reviewers (DC and JM) using Rayyan software [29]. Disagreements at each stage were resolved through discussion and a neutral third party (CP) was consulted if consensus was not reached. The reviewers were not blinded to the authors, journals or results of the studies.

Inclusion criteria are listed in figure 2.

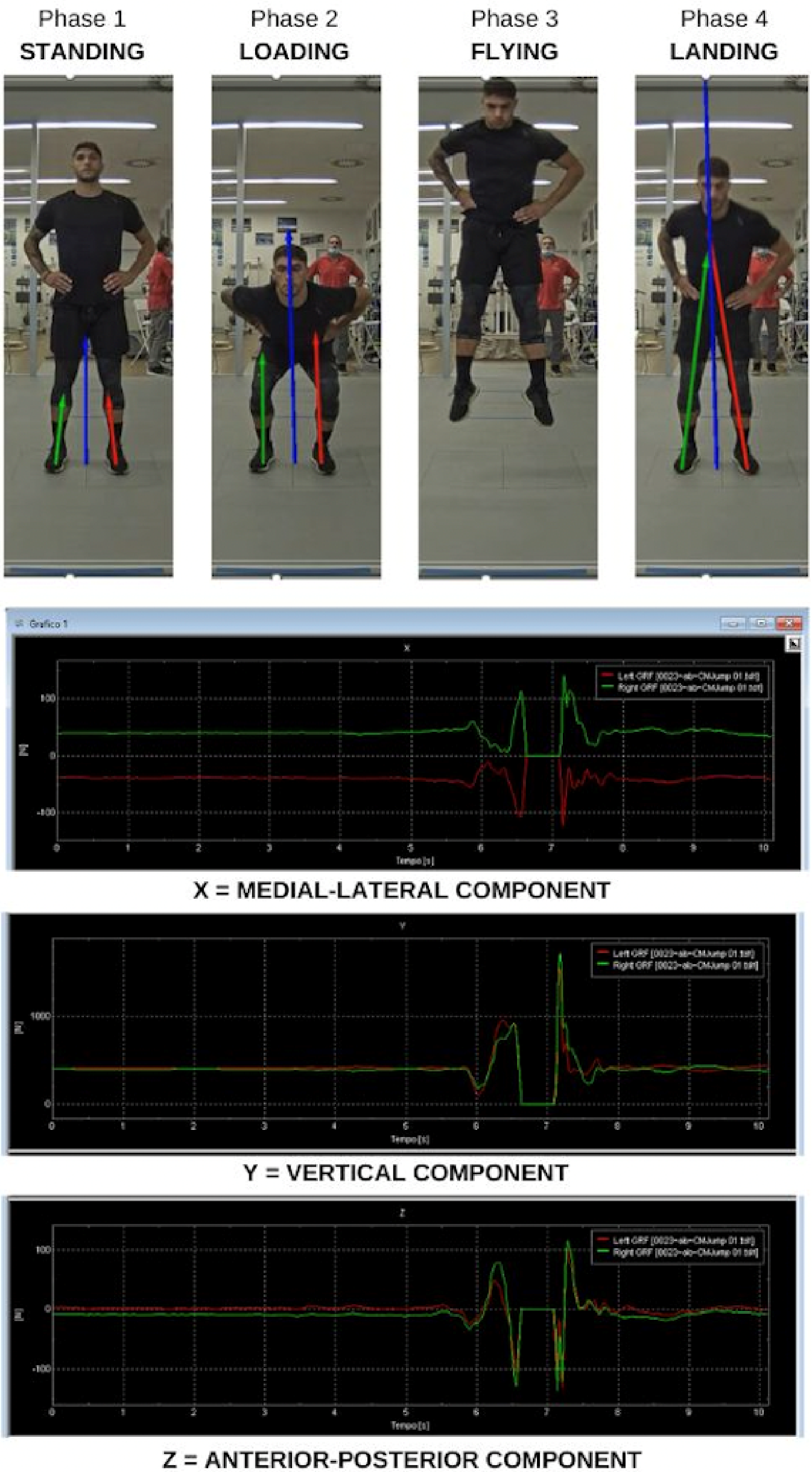

Fig. 1. Main phases of a jump-landing task. Example of the ground reaction force components (Image provided by BTS Bioengineering)

Design
- Randomized controlled trial

Participants
- Healthy young adults, age between 15 and 30 years old
- No history of lower limb injuries

Intervention
- Action observation, also known as observational practice or observational learning, alone or in addition to physical practice
- Delivery mode:
  - Direct observation
  - Video feedback
  - Visual simulation

Outcome measures
- Biomechanical parameters of the lower limb in the sagittal and frontal plane assessed with 2D or 3D motion analysis and force plates

Comparisons
- Non-exposed control group
- Internal focus of attention: feedback or instructions directed toward components of the body movement
- Explicit motor learning: learning generated by verbal knowledge of movement performance

Fig. 2. Inclusion criteria

Risk of Bias assessment

The Revised Cochrane Risk of Bias Tool for Randomized Controlled Trials (RoB 2) [30] was used by two independent reviewers (DC and JM). A third reviewer (CP) was included if there was no consensus. The assessment was made at study level and not at outcome level, because each outcome was measured during the same trial and with the same instruments, so there were not to be differences in the risk of bias. Risk of bias graphical representation was conducted using the robvis tool [31].

Participants characteristics

Data in form of age, gender, country and setting were extracted.

Intervention

The type of jump being analysed and the delivery modality of action observation were collected to assess the characteristics of the intervention. The delivery modality included direct observation of a subject performing a motor task (either a correct model or a learning model); video feedback (a video of a model performing a motor task); visual simulation (video overlay of movement pattern).

Outcome measures

The biomechanical parameters considered for the assessment of the landing technique included peak flexion angles (hip, knee), frontal plane knee displacement (dynamic knee valgus) and ground reaction force (GRF).

Certainty of evidence assessment

The certainty of the body of evidence was assessed by two independent authors (DC and JM) using the GRADE method and the results are presented in the summary of findings table (Appendix 2). The table was produced using GRADEpro GDT software.

Statistical analysis

Two independent authors (DC and JM) extracted data from the reports using a pre-piloted form in Microsoft Excel with cross-checking for differences. Post-intervention data were used to obtain the pooled estimate of the effect of intervention. Data analysis was performed using the latest version of Review Manager (RevMan). A random effect model was used for calculating the pooled estimates, whilst mean difference (MD) was used as an effect size measure when the same instrument was used to measure outcomes and standardized mean difference (SMD) when different instruments were used. Uncertainty of the effect estimate was expressed with 95% confidence intervals (CIs). Statistical heterogeneity was assessed via the I^2 test, with a value greater than 60% considered as substantial heterogeneity. When more than two groups were present in a single study, we first determined which intervention groups were relevant to the review and then combined all relevant experimental groups to create a single pair-wise comparison. To obtain a homogeneous forest plot representation we added a negative sign to the mean scores of the outcomes for which lower scores indicate a better outcome. Due to the low number of studies included in the quantitative synthesis, subgroup and sensitivity analysis were not considered appropriate. The risk of publication bias assessment via a funnel plot was planned only for comparisons where at least 10 studies would have been included in the pooled estimate. No comparisons reached this number of studies, so the risk of publication bias was not assessed.

Results

Flow of studies through the review

The databases and registers search identified 1695 total records. 718 duplicates were deleted. 977 records were screened by title and abstract reading and 929 were excluded. The remaining 48 records were assessed for eligibility by reading the full text. 6 records were included in the review. A flow diagram of the study selection process is reported in figure 3.

Risk of bias

Of the studies included, two [33,35] were assessed as having a low risk of bias, one study [34] had some concerns regarding the randomization process and three

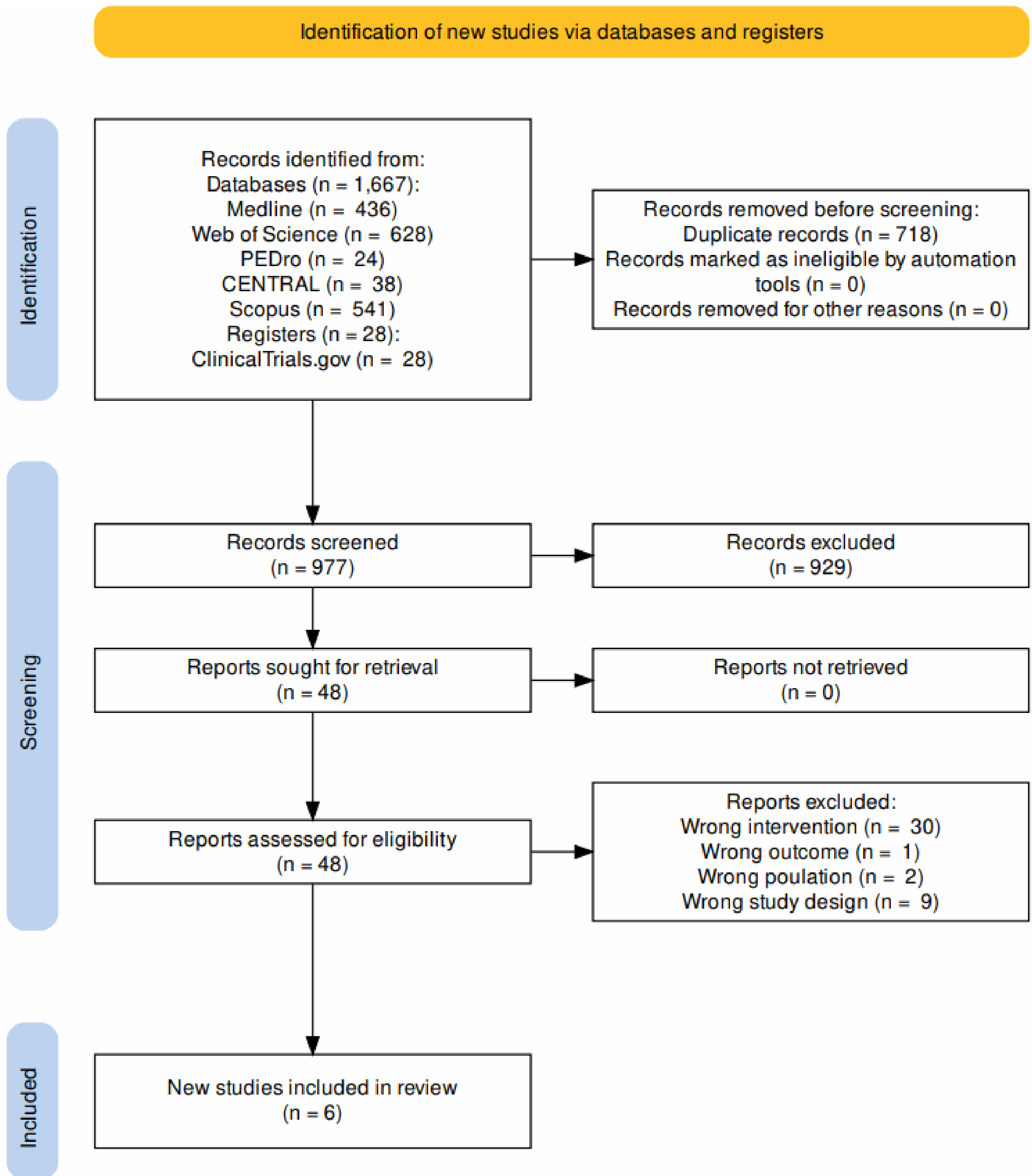

Fig. 3. Flow of studies through the review

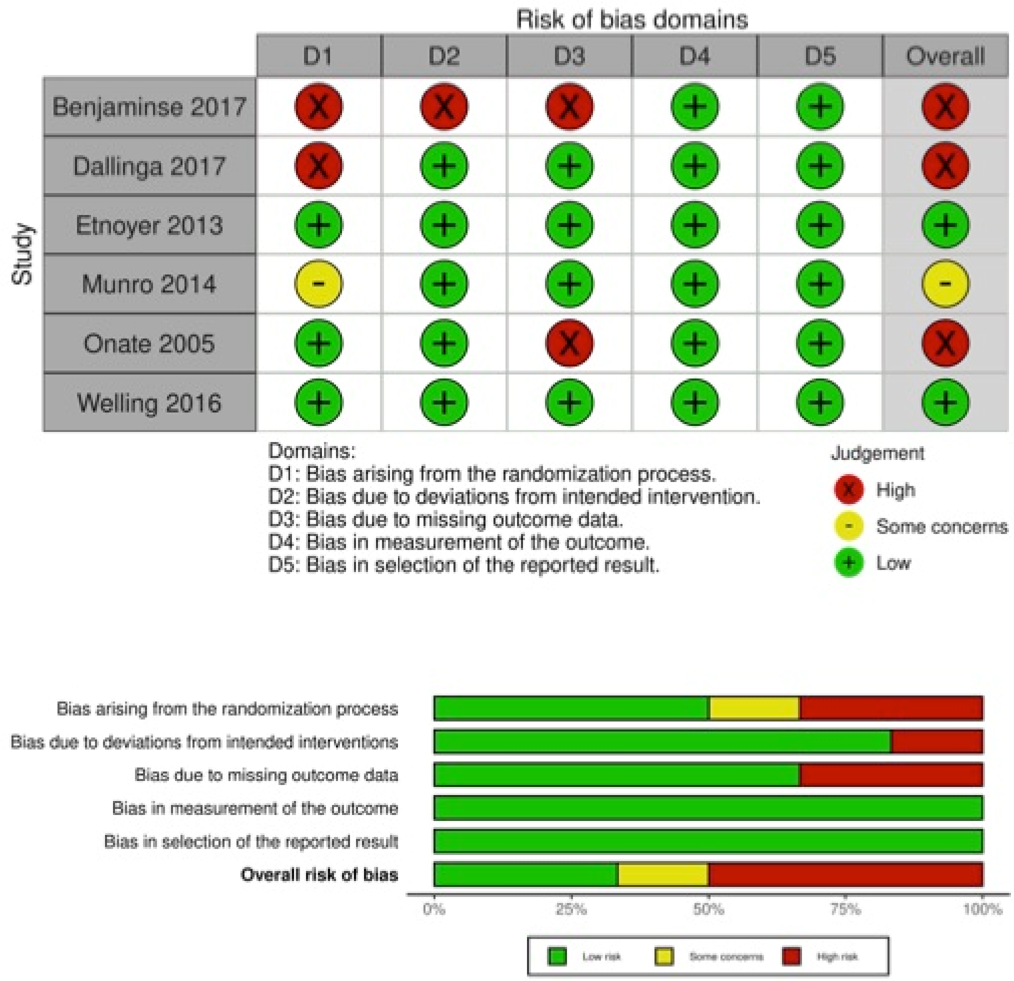

Fig. 4. Risk of bias at overall study level

studies [32,36,37] had a high risk of bias (Fig. 4). The domain with the highest risk of bias across all studies was the randomization process, followed by the missing outcome data and the deviations from interventions. The measurement of the outcome and the selection of the reported result domains were rated as low risk of bias in all studies.

Clinical characteristics

All studies included athletically active healthy young adults. (total: 237; mean age: 22 years old; female: 65%). In 4 studies [32–35], participants performed a drop-vertical jump (DVJ) consisting of a jump to the ground from a box and then immediately afterwards a vertical jump upwards as high as possible. The jump-shot task was performed in one study [36] collecting data from handball players. Participants were asked to "take 3 steps, jump in the air, throw the ball at the goal, and land with 2 feet on the ground". Another study [37], with basketball players as participants, assessed the landing technique of a maximum vertical jump test with a Jump-Ball device. Participants were asked to "perform a single-leg take-off onto the force plates, land with 2 feet, jump into the air to simulate grabbing a basketball, contact a piece of cardboard extended on the Jump-Ball device, and then return to land onto the force plate with 2 feet".

In all the studies, at least one group performed action observation and a non-exposed control group was present. Expert video feedback (a video in which an expert model performs a particular task with the proper technique) was used as the mode of delivery for action observation in all studies

Two studies [33,35] used verbal feedback in addition to video feedback, two other studies [34,37] self-video feedback and one study [36] overlay visual feedback. Despite these differences, all the intervention modalities consisted in the use of observation. Thus, clinical heterogeneity was considered acceptable for the appropriateness of the quantitative synthesis. Detailed characteristics of the studies included are presented in Table 1.

Tab 1. Characteristics of included studies

Study	Design	Participants	Intervention	Outcome measures
Benjaminse et al. (2017) [19]	RCT	n = 16 Age (yr) = 17.7 (SD 1.1) Gender = 0 M, 16 F	Jump task = Jump shot Both = pre-test, 2 training sessions and post-test. Exp = video feedback of an expert model with an overlay of their own jump shots in training sessions 1 and 2 Con = no video feedback	• Peak knee flexion (joint degrees) • Initial contact knee flexion (joint degrees) • Peak hip flexion (joint degrees) • Landing error scoring system (LESS)
Dallinga et al. (2017) [15]	RCT	n = 59 Age (yr) = 23.0 (SD 3.3) Gender = 29 M, 30 F	Jump task = drop vertical jump (DVJ) Both = pre-test, 2 training sessions and a post-test Exp = video feedback of the athlete's contour superimposed onto an expert's contour performing the DVJ landing task in training sessions 1 and 2 Con = no video feedback	• Peak knee flexion (joint degrees) • Peak hip flexion (joint degrees) • Dynamic knee valgus (Nm/Kg) • Vertical ground reaction force (N/Kg)
Etnoyer et al. (2013) [16]	RCT	n = 43 Age (yr) = 21.5 (SD 1.6) Gender = 0 M, 43 F	Jump task = drop vertical jump (DVJ) Both = pre-test, post-test Exp = video feedback of 2 trials of an expert performing DVJ and video feedback of the first 2 trials of their own performance of the DVJ Con = no video feedback	• Peak knee flexion (joint degrees) • Peak hip flexion (joint degrees) • Initial contact knee flexion (joint degrees) • Dynamic knee valgus (joint degrees)
Munro et al. (2014) [17]	RCT	n = 20 Age (yr) = 23.3 (SD 4.2) Gender = 8M, 12 F	Jump task = drop vertical jump (DVJ) Both = pre-test, post-test Exp = video feedback of 2 trials of an expert performing DVJ and video feedback of their own 3 trials Con = no video feedback	• Vertical ground reaction force (%BW) • Dynamic knee valgus (joint degrees)
Onate et al. (2005) [20]	RCT	n = 51 Age (yr) = 18-25 Gender = 19 M, 32 F	Jump task = maximum vertical jump with Jump-Ball device Both = pre-test, post-test Exp = video feedback of 2 trials of an expert performing the maximum vertical jump and video feedback of their own 3 trials Con = no video feedback	• Peak knee flexion (joint degrees) • Initial contact knee flexion (joint degrees) • Vertical ground reaction force (mobs)
Welling et al. (2016) [18]	RCT	n = 40 Age (yr) = 22.5 (SD 1.6) Gender = 20 M, 20 F	Jump task = drop vertical jump (DVJ) Both = pre-test, post-test Exp = video feedback of a contour of an expert video with a perfect performed DVJ Con = no video feedback	• Landing error scoring system (LESS)

Con − control group, – Exp − experimental group, F − female, M − male, n − number of participants randomized, yr − years old

Outcome measures

Five of the studies included [32–34,36,37] provided quantitative data on the biomechanical variables of interest for this review. Thus, the results were included in the quantitative synthesis. Conversely, one study [35] provided only data from a qualitative analysis of the landing technique. Hence, the results of this study were presented narratively. Four studies [32,33,36,37] provided sagittal plane knee measurements through peak flexion angles (joint degrees), whilst knee displacement in the frontal plane was assessed by three studies [32–34] using joint degrees [33,34] and knee valgus moment Nm/Kg [32]. Vertical ground reaction force was assessed in three studies [32,34,37] and the units of measure were N/Kg [32], % of body weight (%BW) [34] and multiple of body weight (mBW) [37].

Peak knee flexion

The effect of action observation versus control on peak knee flexion was estimated by pooling outcomes from four trials [32,33,36,37] involving 135 participants (Fig. 5A). The effect size was large to moderate (MD 15.95, 95% CI 3.53 to 28.38, $I^2 = 92\%$) in favour of action observation. The certainty of evidence of this

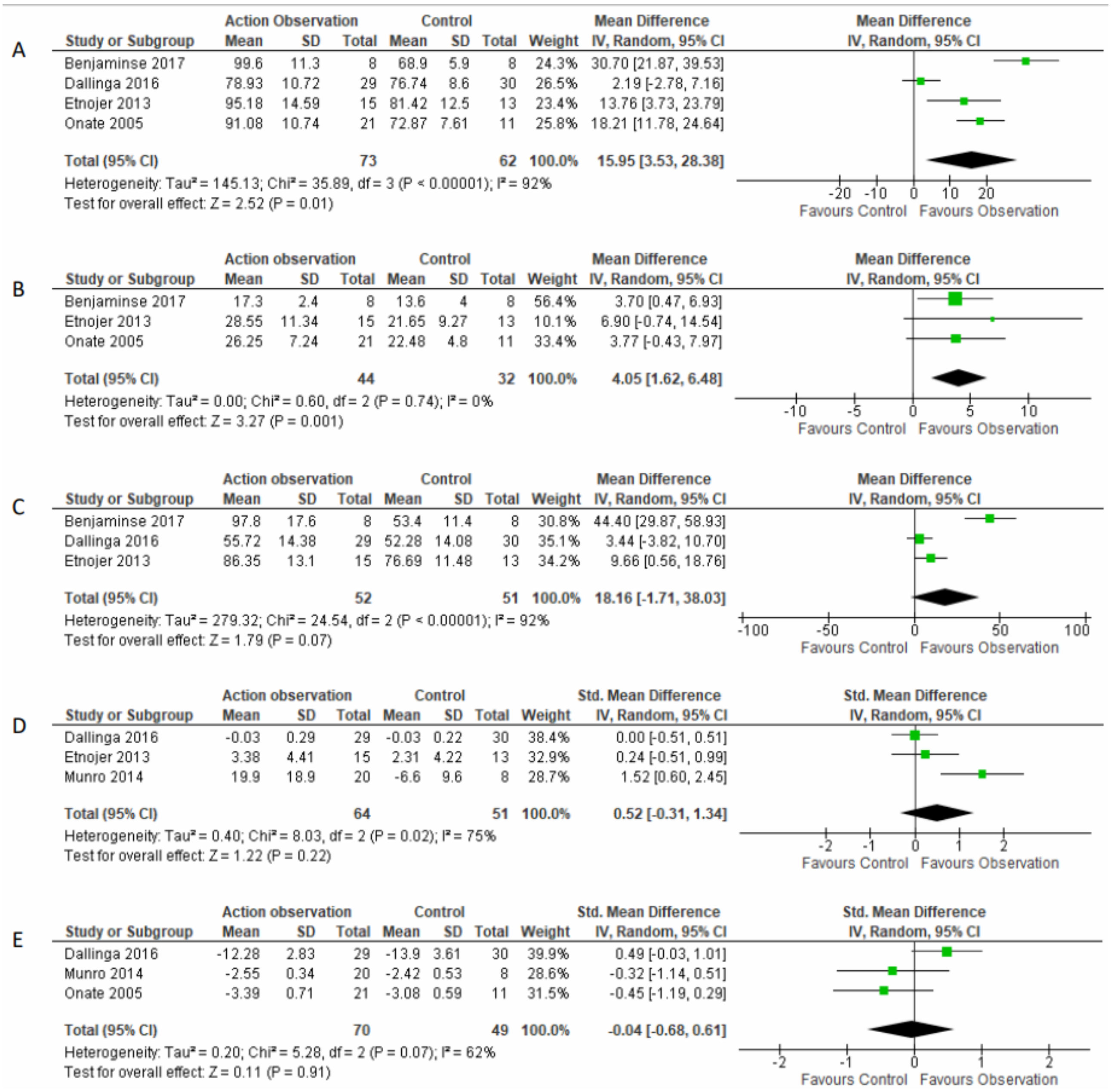

Fig. 5. Forest plots of the results of random effects meta-analysis on the effects of action observation on: (A) Peak knee flexion; (B) Initial contact knee flexion; (C) Peak hip flexion; (D) Dynamic knee valgus; (E) Vertical ground reaction force

Tab. 2. Mean (SD) Landing Error Scoring System Score (LESS) at post-test for each group and mean (95% CI) difference between groups

Study	Groups		Difference between groups
	Action observation	Control	Action observation minus control
Welling et al. (2016)[18]	2.04 (0.67)	3.1 (0.69)	–1.06 (–1.66 to –0.46)
Benjaminse et al. (2017) [19]	4.00 (1.30)	8.1 (0.30)	–4.10 (–5.02 to –3.18)

outcome was rated as very low due to the serious risk of bias and very serious inconsistency.

Initial contact knee flexion

Three trials [33,36,37] involving 76 participants investigated the effect of action observation versus the control on initial contact knee flexion (Fig. 5B). The pooled estimate was moderate (MD 4.05, 95% CI 1.62 to 6.48, $I^2 = 0\%$) in favour of action observation. The certainty of evidence was moderate, downgraded for risk of bias.

Peak hip flexion

A pooled effect of three studies [32,33,36] allowed us to estimate the effect of action observation versus control on peak hip flexion with a total of 103 participants (Fig. 5C). The effect size ranged from large to no effect (MD 18.16, 95% CI – 1.71 to 38.03, $I^2 = 92\%$) in favour of action observation. The certainty of evidence was very low with the risk of bias and inconsistency being the causes of downgrading.

Dynamic knee valgus

Action observation showed moderate to no effect on dynamic knee valgus (SMD 0.52, 95% CI – 0.31 to 1.34, $I^2 = 75\%$) compared to the control (Fig. 5D). Effect size was calculated by pooling the results from three trials [32–34] including 115 participants. Due to the risk of bias and inconsistency, the certainty of evidence was rated as low.

Vertical ground reaction force

Pooled effect size from three studies [32,34,37] including 119 participants showed no effect of action observation versus the control on vertical ground reaction force (SMD – 0.04, 95% CI – 0.68 to 0.61, $I^2 = 62\%$) (Fig. 5E). Very low certainty of evidence was rated for this outcome due to serious risk of bias, inconsistency and imprecision.

Qualitative landing biomechanics assessment

A qualitative assessment of the landing technique was performed in two studies [35,36] using the landing error scoring system (LESS), which is a valid and reliable tool for identifying potentially high-risk movement patterns during a jump-landing task [38]. In both studies, action observation groups showed lower LESS scores, indicating a better landing technique at post-test compared to the control groups (Tab. 2).

Discussion

Action observation was shown to potentially improve lower limb landing biomechanics. Both initial contact and peak knee flexion angles showed larger to moderate improvements compared to control groups. Several studies demonstrated that ACL loading increases as knee flexion angle decreases [39–41] so the ability to land from a jump with higher knee flexion angles reduces ACL strain and potentially reduces the risk of injury. This could be considered a promising finding because, although the certainty of evidence of peak knee flexion outcome was rated as very low, the quality of evidence regarding initial contact knee flexion was moderate, so we could be quite confident in the validity of this result.

Along with knee flexion angles, the hip flexion angle also represents an important variable for ACL loading forces. Landing movement patterns associated with a lower risk of injuries are those with higher hip flexion angles [42,43]. The results of the pooled estimate showed the potential benefits of action observation in increasing peak hip flexion angles, although confidence in this outcome is low.

Although the limitations emerging from the studies included in the quantitative synthesis result in overall low confidence in the estimation of effects, all the three outcomes mentioned earlier (peak knee flexion, initial contact knee flexion and peak hip flexion) demonstrated encouraging results in favour of action observation in improving sagittal plane landing biomechanics.

Another important plane of movement of the lower limb is the frontal plane, where knee displacement towards the mid-line of the body represents the main variable of interest. In particular, an increased medial knee displacement during landing (dynamic knee valgus) is considered a risk factor for ACL injuries [44]. Some authors argue that DKV alone is not likely to be a major risk factor for sustaining an ACL injury. However, when combined with other factors such as proximal tibia anterior shear force, it significantly affects ACL loading [45−47]. Despite the association between knee valgus angle and non-contact ACL injuries not being fully understood, a reduction in this parameter can surely contribute to lower overall knee loading forces during landing. This parameter was affected to a moderate degree by action observation, although the confidence interval shows some uncertainty in the estimate.

The force exerted by the ground on a body in contact with it, also known as ground reaction force, is another parameter that should be considered when assessing lower extremity biomechanics. The main components of the ground reaction force are the vertical and the horizontal (frictional) forces. Usually, when assessing the landing biomechanics, researchers mainly focus on the vertical component of the ground reaction force although the horizontal component may also play an important role, especially when landing on a rough surface (frequent in outdoor sports). The studies included in this review follow this trend, so the horizontal component of the ground reaction force has not been analysed. For this reason, we can only discuss the results obtained for the vertical ground reaction force and be aware that oblique forces also involve the risk of injury. Evidence from different studies suggests that a higher vertical ground reaction force during landing may be a risk factor for sustaining an ACL injury [43,48]. Contrary to what we observed in the other outcomes, action observation showed no effect in the terms of reducing the vertical reaction force compared to the control. This result could raise some doubts, considering the positive effect estimates obtained for the other biomechanical outcomes in the sagittal and frontal plane. In fact, one would expect a similar result for the vertical ground reaction force as well. Nonetheless, another study [48] suggested that large hip and knee flexion angles at the initial foot contact with the ground do not necessarily reduce impact forces during a landing task, but active hip and knee flexion motions do. Therefore, we can assume that action observation improves joint flexion angles during landing, although it does not affect the dynamics of muscle activation, which would result in a reduction of ground reaction force.

To strengthen the hypothesis that action observation contributes in a positive way to the motor learning of a better landing technique, we could consider the results from a qualitative perspective through the LESS score. All the studies that included this outcome showed an improvement in the total score for the observational groups compared to the control. Hence, although no statistical aggregation of this data was performed, we can interpret these results in light of the considerations made for the biomechanical variables, which suggest that action observation is effective in improving the landing technique.

A relevant aspect for putting the results described so far into clinical practice is the cost-effectiveness of action observation. In the case of video feedback (observation of a video of a model performing a motor task), the only equipment required is a device that shows the video (a tablet or a video projector). In the direct observation of a model performing a motor task, no equipment is required as, for example, the model could be a teammate that performs a specific task with proficient technique. We can therefore state that action observation is an inexpensive and time-efficient practice.

The main limitations of this study are the small number of trials included, together with an overall high risk of bias. These limitations are reflected in the overall low certainty of the body of evidence. Nonetheless, the outcomes showed the same direction of the effect estimates, which suggests that the results of this study can be taken into consideration for clinical practice.

Considering the challenges of the rehabilitation of an ACL injury [49], an interest topic for further research could be to investigate the effects of action observation in the lower limb landing biomechanics of subjects that have undergone ACL reconstruction in order to assess the effectiveness of action observation in reducing ACL re-injury risk factors.

Conclusions

In conclusion, action observation is an inexpensive, simple and time-efficient practice that can enhance motor learning of a proper landing technique by improving peak and initial contact knee flexion, peak hip flexion and reducing dynamic knee valgus. Vertical ground reaction force does not seem to be affected by action observation; therefore, further studies might try to analyse other methods for reducing this injury risk. ACL injury prevention programs could improve their effectiveness by implementing action observation along with physical training without adding many resources, although high-quality clinical trials are needed to confirm this hypothesis.

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Conflicts of Interest
The authors have no conflict of interest to declare.

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