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Real-time feedback on knee abduction moment does not improve frontal-plane knee mechanics during jump landings

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Excessive knee abduction loading is a contributing factor to anterior cruciate ligament (ACL) injury risk. The purpose of this study was to determine whether a double-leg landing training program with real-time visual feedback improves frontal-plane mechanics during double- and single-leg landings. Knee abduction angles and moments and vertical ground reaction forces (GRF) of 21 recreationally active women were quantified for double- and single-leg landings before and after the training program. This program consisted of two sessions of double-leg jump landings with real-time visual feedback on knee abduction moments for the experimental group and without real-time feedback for the control group. No significant differences were found between training groups. In comparison with pre-training data, peak knee abduction moments decreased 12% post-training for both double- and single-leg landings; whereas peak vertical GRF decreased 8% post-training for double-leg landings only, irrespective of training group. Real-time feedback on knee abduction moments, therefore, did not significantly improve frontal-plane knee mechanics during landings. The effect of the training program on knee abduction moments, however, transferred from the double-leg landings (simple task) to single-leg landings (more complex task). Consequently, ACL injury prevention efforts may not need to focus on complex tasks during which injury occurs.

Injury of the anterior cruciate ligament (ACL) has been the main focus of many research endeavors (Renstrom et al., 2008) given its extensive health and financial consequences (Griffin et al., 2006; Hewett et al., 2006; Lohmander et al., 2007; Neuman et al., 2008). In fact, several mechanisms of injury, along with their risk factors, have been proposed (Shimokochi & Shultz, 2008; Quatman et al., 2010). One such mechanism, as observed from video sequences of ACL injuries (Krosshaug et al., 2007; Boden et al., 2009), is that of knee "valgus collapse" which comprises abduction of the knee joint, in combination with hip adduction, hip internal rotation, and tibial rotation (Quatman & Hewett, 2009). Supported by *in vivo* laboratory-based studies, excessive knee abduction during "risky" athletic maneuvers such as landings, therefore, has been suggested to be a contributing factor to injury risk. Frontal-plane knee mechanics, for example, have prospectively predicted ACL injury, with greater abduction linked to ligament rupture (Hewett et al., 2005). Also, females, which have greater risk of ACL injury than males, have been shown to land with greater knee abduction (Russell et al., 2006; Gehring et al., 2009; Sigward et al., 2011). Consequently, prevention efforts that target frontal-plane mechanics during landing tasks have been developed (Alentorn-Geli et al., 2009). Although these programs have revealed early successes, high ACL injury rates and their sex disparity remain (Agel et al., 2005). Perhaps, a different approach to ACL injury prevention is needed.

Real-time feedback has been shown to significantly improve joint biomechanical parameters known to contribute to risk of developing joint disorders, such as tibiofemoral joint osteoarthritis and patellofemoral pain syndrome (Hunt et al., 2011; Noehren et al., 2011; Shull et al., 2011; Wheeler et al., 2011). Hence, this type of feedback may also be capable of modifying frontal-plane knee landing mechanics associated with ACL injury risk, although this has yet to be determined. The purpose of this study, therefore, was to determine the effect of a double-leg landing training program with real-time feedback on frontal-plane mechanics during double-leg landings. It was hypothesized that real-time feedback on knee abduction moments would significantly decrease these moments, as well as knee abduction angles. A secondary purpose was to investigate the cross-task transferability of the double-leg landing training program by determining its effect on frontal-plane mechanics during single-leg landings. Most ACL injury prevention programs seek to improve the biomechanics of relatively simple and controlled movements (Hewett et al., 1996; Myer et al., 2006; Barendrecht et al., 2011); yet, most non-contact ACL injuries occur during complex single-leg deceleration tasks (Olsen et al., 2004; Boden et al., 2009). It was hypothesized that a double-leg landing training program would decrease frontal-plane knee mechanics during double-leg landings, but not those occurring during single-leg landings.

Materials and methods

Participants

A total of 21 women, between the ages of 18 and 24, participated in the current study, 11 of which received real-time feedback (feedback group: age = 21.9 ± 1.8 years; height = 165.8 ± 5.5 cm; mass = 60.9 ± 10.8 kg) and 10 of which did not receive feedback (control group: age = 21.2 ± 2.2 years; height = 164.4 ± 5.3 cm; mass = 62.6 ± 8.7 kg) during the double-leg landing training program. All participants were recreationally active [minimum of 30 min of physical activity, at least three times a week (Schmitz et al., 2007)], with most women active by means of running/jogging. They were also free of any current lower-limb injury, had not suffered any major knee injury, had not undergone any lower-limb surgery, had not suffered any lower-limb injuries in the past 6 months, did not suffer from a heart condition, and were not pregnant. To determine leg dominance, each participant was asked with which foot they would kick a soccer ball. Research activities were approved by the Institutional Review Board. All participants gave their informed consent.

Protocol

All volunteers participated in four sessions: (a) an initial data collection session during which lower-limb biomechanics of double- and single-leg landings were recorded; (b–c) a double-leg landing training program consisting of two training sessions during which double-leg jumps for maximal height were performed; and (d) a second, post-training data collection session identical to the initial session (Fig. 1). All four sessions occurred two to three days apart.

During the initial and second data collection sessions, three-dimensional (3D) motion of both lower limbs and ground reaction forces (GRF) were recorded during double- and single-leg landings. GRF data were recorded at 1200 Hz via two force platforms (model OR6-6, Advanced Mechanical Technology Inc., Watertown, Massachusettes, USA) imbedded into the ground 25.3 cm apart. Motion data were obtained by means of retro-reflective markers affixed to the skin (with the exception of those markers affixed to the shoes) recorded with an 8-camera motion capture system (camera model MX-13, Vicon, Los Angeles, California, USA) at 240 Hz. Due to the sensitivity of joint rotations and moments to marker placement, anatomical landmarks from which joint centers and segmental coordinate systems were defined were marked with a permanent marker during the initial testing session. These landmarks were the right and left anterior and posterior superior iliac spines and the medial and lateral femoral epicondyles. This process ensured that changes in knee mechanics between sessions were due to actual changes, and not due to variability in marker placement.

The double-leg landing task consisted of a drop landing from a 31.5-cm platform onto the force platforms followed immediately by a maximum vertical jump (Fig. 2(a)), as previously described (Ford et al., 2010). The single-leg landing task consisted of a vertical jump to grab a basketball suspended at a height of 80% of the participant's maximum vertical jump height, a single-leg landing, and an immediate lateral cut in the opposite direction of the landing foot (e.g., landing on the right following by a cut to the left) (Fig. 2(b)). The basketball was suspended at this height, as previously utilized (Myer et al., 2002), because pilot testing revealed that participants were unable to consistently jump and successfully grab the ball when it was suspended at their maximum jump height. Single-leg landings were performed for each foot, in a random order. Participants performed several practice jumps to familiarize themselves with the maneuvers and to warm up. The landing maneuvers were then performed until eight double-leg and 16 single-leg (eight trials with each foot) trials were successfully completed. For the double-leg landings, a trial was deemed unsuccessful if the participant (a) stepped off (i.e., single-leg take-off) or jumped off the platform as opposed to dropping off with both feet simultaneously, (b) did not land with both feet completely on each force platform, (c) did not jump completely vertically, (d) and/or did not jump with a maximum effort, as visually observed by the investigator. For the single-leg landings, a trial was rejected if the participant fumbled the basketball, did not land with their foot completely on the appropriate force platform, and/or did not cut completely laterally. Biomechanical data from the stance phase of the landings tasks were extracted for analyses. The stance phase was defined as initial ground contact (IC) to toe-off of the landing phase occurring immediately after the drop jump and the vertical jump for the double- and single-leg landing maneuvers, respectively.

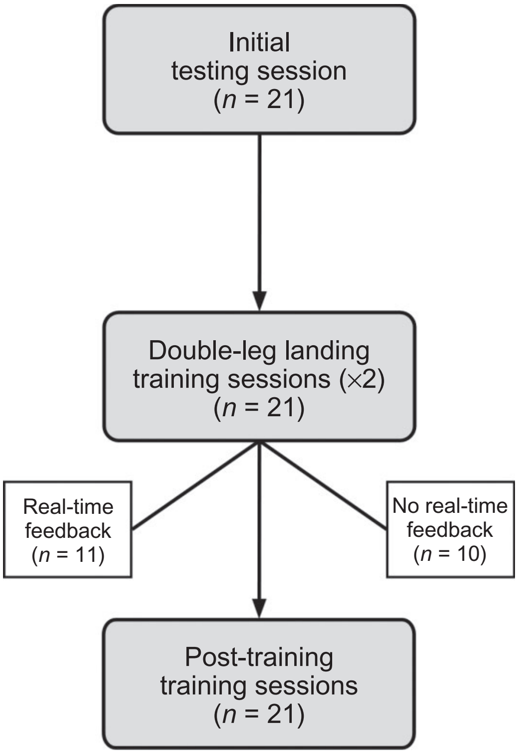

Fig. 1. Study protocol. Following the initial testing session, all participants took part in two double-leg landing training sessions. They were randomly assigned to one of two groups: (a) with real-time visual feedback or (b) without real-time visual feedback. Then, participants attended a post-training testing session. Rounded rectangle boxes represent the testing/training sessions, which occurred two to three days apart.

Biomechanical analyses

From retro-reflective markers placed on specific anatomical landmarks and recorded during a static reference trial, a kinematic model that comprised seven segments (right and left foot, shank, and thigh segments and the pelvis) was defined. During the static trial, the participants stood in a neutral position, with feet

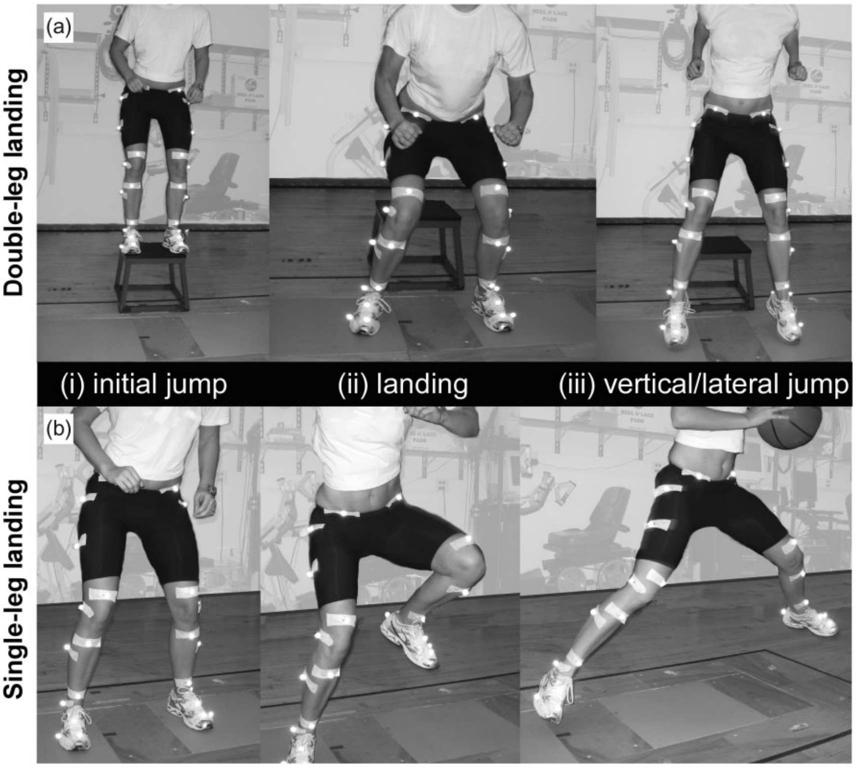

Fig. 2. A participant performing the double-leg drop jump landing (a) and single-leg jump landing (b) maneuvers. Participants executed the initial jump (i) with both feet. Biomechanical data of the landing phase (ii) was used for analysis. Following the double- and single-leg landings, vertical and lateral jumps (iii) were executed, respectively.

shoulder-width apart and pointing anteriorly and knees fully extended (but not hyperextended). Knee and ankle joint centers were defined as the midpoints between the medial and lateral femoral epicondyles and between the medial and lateral malleoli, respectively. As for the hip joint, a functional joint center was calculated with Visual 3D software (version 4.00, C-Motion, Inc., Germantown, Maryland, USA), which used a method adapted from Schwartz and Rozumalski (2005).

Three-dimensional joint rotations and moments were calculated in Visual 3D software. Prior to these calculations, markers' 3D coordinates and GRF data were low-pass filtered with a Butterworth filter (fourth order, zero lag, 12 Hz cut-off frequency). Rotations at the hip, knee and ankle joints were expressed as the orientation of the distal segment in relation to the proximal segment, as well as relative to each participant's neutral standing position. Lower-limb joint moments were calculated by means of a conventional inverse dynamics analysis. Three-dimensional knee joint moments were resolved in the tibial coordinate system and are expressed as external moments.

Double-leg landing training program

Following the initial testing session, one of two training programs was randomly assigned to each participant: (a) a double-leg landing training program with real-time visual feedback; or (b) a double-leg landing training program without such feedback. A third group not participating in a double-leg landing training program was not included because the effect of such a program has been investigated (Onate et al., 2001) and thus was not of interest. Our interest rather, was to determine the effect of real-time visual feedback on the knee abduction moment. For each group, the training program consisted of two sessions, during which six sets of five consecutive double-leg maximum vertical jumps were performed, with the foot of the dominant leg on one of the force platforms. This task was selected, as opposed to the drop jump-landing task executed during the initial session, to provide the participants with the ability to immediately modify their landing technique following feedback. Each participant was allocated a 60-s rest period between each set of jumps to avoid fatigue. Prior to the start of each session of the training program, retro-reflective markers were placed on the participant, as previously described, after which they performed several consecutive vertical jumps to familiarize themselves with the task. Also, the following verbal instructions were given before the start of training, as well as half way into training as a reminder: (a) keep your feet shoulder-width apart; (b) jump straight up without side-to-side or forward-backward movement; and most importantly (c) keep your knees "over your feet" (Hewett et al., 1996; Myer et al., 2005). The same instructions were given to all participants regardless of their landing technique. A demonstration was also given to each participant by the same expert model. By providing the same instructions and demonstration to all participants, the possible effect of such information was assumed to be the same for all participants and thus was assumed not to be a confounding factor.

For the feedback group, knee abduction moment of their dominant leg was provided, in real-time, via a two-dimensional graph projected onto the wall directly in front of them using Visual 3D software (Fig. 3). In addition to the instructions aforementioned, the participants were also instructed to minimize their knee abduction moment (i.e., keep moment line as close as possible to zero) while maintaining it below a pre-determined threshold. This threshold was defined as 75% of the participant's peak knee abduction moment produced during the double-leg drop landings of the initial testing session. It was based on average percentage reduction in peak knee abduction moment previously reported for landing tasks as a result of training programs (Hewett et al., 1996; Myer et al., 2005, 2007; Cochrane et al., 2010). The participants were told that they would be able to minimize this moment by

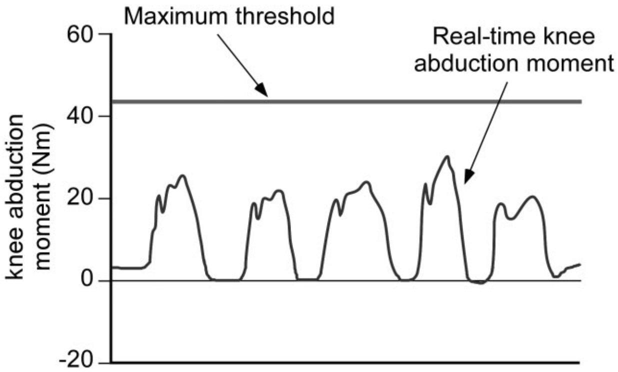

Fig. 3. Sample of the real-time visual feedback display projected onto the laboratory wall directly in front of the participants in the feedback group. Participants were instructed to maintain their knee abduction moment below the maximum threshold, which represented 75% of their average peak knee abduction moment measured during the initial testing session for the double-leg landing task.

keeping their "knees over their feet", and thus avoiding a "knock-kneed" position. These instructions were based on the fact that, generally speaking, the moments produced at the knee joint are dictated by the direction of the resultant GRF relative to the center of the joint (Powers, 2010). Hence, medial/lateral motion of the knee joint center can increase/decrease the knee abduction moment, respectively. No feedback was given to the control group.

Statistical analysis

Knee abduction angles at IC, peak knee abduction angles, peak knee abduction moments, and peak vertical GRF were extracted for the dominant leg from the single- and double-leg landing trials. Peak angles and moments were identified from the landing phase of stance, defined as 0% stance to peak knee flexion angle. ACL injuries have been reported to occur within this time frame (Krosshaug et al., 2007). Peak vertical GRF data were normalized to the participant's body weight (BW), and thus reported as a multiple of body weight (*BW). Subsequently, the dependent variables were averaged over all trials ($n = 8$) for each landing type. To test our hypotheses, each variable was compared between time points (pre- vs post-training), groups (feedback vs control), and landing types (single- vs double-leg) by means of a three-way analysis of variance (ANOVA). Specifically, results from the time by group by landing type interaction, as well as the time by group interaction, tested our main hypothesis that a double-leg landing training program with real-time feedback on knee abduction moments would significantly decrease knee abduction angles and moments during double-leg landings. Results from the time by landing type interaction tested our secondary hypothesis that the training program would decrease frontal-plane knee mechanics during double-leg landings, but not those occurring during single-leg landings. Statistically significant interactions were followed up with one-way repeated measures ANOVAs to determine where the difference occurred. A P-value less than 0.05 indicated statistical significance. The magnitude of the effects was estimated by means of the partial eta squared (η_p^2), where 0.01, 0.06, and 0.14 represent small, moderate, and large effects, respectively (Stevens, 2001). All statistical analyses were performed with SPSS software (version 19.0, IBM Corporation, Armonk, New York, USA).

Results

Average biomechanical data of double- and single-leg landings, grouped by testing session, are presented in Table 1 for each training group. All participants in the feedback group were able to maintain their knee abduction moment below the displayed threshold during both sessions of the double-leg landing training program.

Results from the three-way ANOVAs revealed no effect of real-time feedback during the training program on any of the biomechanical parameters assessed during double- and single-leg landings (interaction effect of time, group and landing type: $P > 0.05$; interaction effect of time and group: $P > 0.05$). These results did reveal, however, an effect of the training program that was dependent on landing type, but only for peak vertical GRF (interaction effect of landing type and time: $P = 0.005$, $\eta_p^2 = 0.351$). Further analyses using one-way repeated measures ANOVAs showed that, regardless of training group, peak vertical GRF decreased from the initial (pre-training) data collection session to the second (post-training) data collection session for the double-leg landings ($P = 0.006$, $\eta_p^2 = 0.317$; pre: 1.8 ± 0.1*BW; post: 1.7 ± 0.1*BW); whereas jump-landing training had no effect on this force for the single-leg landings ($P = 0.467$, $\eta_p^2 = 0.027$; pre: 2.7 ± 0.1*BW; post: 2.7 ± 0.1*BW).

Furthermore, the peak knee abduction moment significantly decreased following jump-landing training [main effect for time: $P = 0.044$, $\eta_p^2 = 0.198$; pre: 0.25 ± 0.03 Nm/(kg*m); 0.22 ± 0.02 Nm/(kg*m)], regardless of training group and landing type. Significant differences were also revealed between double- and single-leg landings for knee abduction angle at IC (main effect for landing type: $P < 0.001$, $\eta_p^2 = 0.651$), peak knee abduction moment (main effect for landing type: $P < 0.001$, $\eta_p^2 = 0.637$), and peak vertical GRF (main effect for landing type: $P < 0.001$, $\eta_p^2 = 0.927$), regardless of training group and testing session. Specifically, knee abduction angle at IC (single: −1.3 ± 0.4°; double: −0.4 ± 0.4°) and peak vertical GRF (single: 2.7 ± 0.1*BW; double: 1.8 ± 0.1*BW) were greater during single-leg landings; whereas peak knee abduction moment [single: 0.16 ± 0.03 Nm/(kg*m); double: 0.30 ± 0.02 Nm/(kg*m)] was greater during double-leg landings. The significant difference in knee abduction angle at IC between landing types appear to have been driven by the control group given that a significant landing type by training group interaction was found for this kinematic variable (interaction effect of landing type and group: $P = 0.031$, $\eta_p^2 = 0.222$). One-way repeated measures ANOVAs showed that, regardless of testing session, initial knee abduction angle was greater during the single-leg landings than the double-leg landings for both groups, with this difference being larger in the control group (control: $P < 0.001$, $\eta_p^2 = 0.799$, single: −1.0 ± 0.5° vs double: 0.3 ± 0.6°; feedback: $P = 0.030$, $\eta_p^2 = 0.390$, single: −1.6 ± 0.5°, double: −1.1 ± 0.6°).

Lastly, no significant differences were found for peak knee abduction angles (all interactions and main effects: $P > 0.05$). No significant differences were found

Table 1. Average (and standard deviation) knee abduction angles and moments measured during double- and single-leg landings, before and after the double-leg landing training program

		Feedback		Control	
		Pre-training	Post-training	Pre-training	Post-training
Angle at IC† (deg)	double-leg	–1.2 (1.6)	–1.0 (2.1)	0.5 (1.9)	0.0 (2.2)
	single-leg	–1.8 (1.3)	–1.5 (1.6)	–0.8 (1.9)	–1.3 (2.2)
Peak angle (deg)	double-leg	–4.4 (3.0)	–3.7 (3.4)	–1.8 (2.6)	–2.5 (3.1)
	single-leg	–3.6 (2.5)	–3.6 (2.8)	–2.1 (2.5)	–3.3 (2.8)
Peak moment‡ [Nm/(kg*m)]	double-leg	0.36 (0.09)	0.31 (0.10)	0.28 (0.11)	0.27 (0.11)
	single-leg	0.19 (0.14)	0.17 (0.14)	0.15 (0.16)	0.13 (0.15)
Peak vertical GRF (*BW)	double-leg	1.8 (0.3)	1.7 (0.3)	1.9 (0.4)	1.7 (0.3)
	single-leg	2.7 (0.3)	2.7 (0.2)	2.7 (0.3)	2.7 (0.4)

†Knee abduction angles are negative.

‡Knee abduction moments are positive.

BW, body weight; IC, initial ground contact.

between training groups for any of the biomechanical parameters, irrespective of landing type and time (main effect for group: $P > 0.05$).

Discussion

The present investigation examined the effect of a double-leg landing training program with real-time visual feedback on frontal-plane knee mechanics during double-leg landings. Contrary to the expected outcome, real-time feedback on knee abduction moment did not reduce frontal-plane knee mechanics known to be contributing factors to ACL injury risk or peak vertical GRF. This study also investigated the cross-task transferability of the double-leg landing training program by determining its effect on frontal-plane knee mechanics during single-leg landings. The effect of the training program was found to transfer from double- to single-leg landings for peak knee abduction moments. These moments decreased from pre- to post-training during both double- and single-leg landings, regardless of real-time feedback. This cross-task transferability, however, was not observed for peak vertical GRF.

Our first hypothesis that real-time feedback on knee abduction moments would decrease knee abduction angles and moments during double-leg landings was not accepted. Although the effect of real-time feedback on knee landing mechanics has never been investigated, to our knowledge, similar results have been reported by Herman et al. (2009) with delayed feedback. Their participants received verbal feedback and instructions during video replay of their performance of a jump-landing maneuver and that of an expert model jump landing, after which they repeated the task. Repeated on three occasions, the feedback protocol did not improve frontal-plane knee mechanics. The protocol, however, did successfully reduce ground impact forces and increase knee flexion, hip flexion, and hip abduction angles. In light of these positive effects of delayed feedback on landing biomechanics and those outcomes supporting the effectiveness of real-time feedback on joint mechanics (Hunt et al., 2011; Noehren et al., 2011; Shull et al., 2011; Wheeler et al., 2011), it appears that a revised version of our feedback protocol may modify frontal-plane knee mechanics and/or vertical GRF. Perhaps, the concept of knee moments in the frontal-plane was too complex for the participants to grasp, and therefore to effectively use this real-time feedback to improve their knee landing mechanics. Perhaps feedback focused on the desired result of lower knee abduction moments during landing ("knowledge of results") was too abstract to the participants. If so, a simpler variable focused on the performance needed to achieve the desired result ("knowledge of performance"), such as the ratio between inter-knee distance and inter-ankle distance, may yield greater improvement. This is of particular interest as the magnitude of this variable is dependent on frontal- and transverse-plane mechanics, both at the hip and knee. It is well accepted that the mechanism of ACL injuries is multi-planar (Quatman et al., 2010).

Our second hypothesis that a double-leg landing training program would decrease frontal-plane knee mechanics of double-leg landings, but not those of single-leg landings could not be accepted. In fact, it was rejected for peak knee abduction moment given that this parameter decreased by 12% from the initial (pre-training) data collection session to the second (post-training) data collection session for both double- and single-leg landings, irrespective of real-time feedback. This outcome reveals the cross-task transferability of the training with respect to knee abduction moments, contrary to expected results. The participants, therefore, were able to partly transfer the learning acquired for the double-leg landings during training – through verbal instructions, demonstration, and practice – to the (more complex) single-leg landing task, which involved jumping, grabbing a basketball, landing, and cutting. This cross-task transferability of training, however, was not observed for the landing impact force. Regardless of whether real-time visual feedback was provided, peak vertical GRF decreased by

8% from the pre-training to the post-training data collection session for the double-leg landings; whereas training had no effect on this force for the single-leg landings. It was not possible to determine whether the effect of the double-leg landing training program is transferable across tasks (i.e., single-leg landings with lateral movement) for the knee abduction angle parameters, however, given that the training program did not have any effect on them during double-leg landings. The cross-task transferability of ACL injury prevention programs is imperative because most programs are aimed at improving joint mechanics during relatively simple and controlled movement, such as planar double-leg landings (Hewett et al., 1996; Myer et al., 2006; Barendrecht et al., 2011; Nyland et al., 2011). Yet, most non-contact ACL injuries occur during multi-planar single-leg decelerations tasks, such as single-leg pivot landings (Olsen et al., 2004; Boden et al., 2009). Depending on the desired biomechanical outcome of training, prevention efforts aimed at improving neuromuscular control may not need to focus on these tasks specifically. They may focus on tasks different in nature and complexity that may be incorporated more easily in an injury prevention program.

Furthermore, knee abduction angle at IC, peak knee abduction moment, and peak vertical GRF differed between types of landing maneuvers. Differences between double- and single-leg landings have been reported previously, with greater knee abduction angles during the single-leg landing and similar vertical GRFs between landing types (Pappas et al., 2007). Knee abduction moments were not reported. Upon landing, however, the participants were not instructed to perform a jump, contrary to the present study. The differences found in our investigation, therefore, most likely stem from the nature of the jump executed upon landing. During the double-leg landing task, our participants performed a maximum vertical jump upon landing from the drop jump. During the single-leg landing task, however, a lateral jump-cut was executed upon landing. Interestingly, Sell et al. (2006) also found that knee joint mechanics were dependent on jump direction, concluding that lateral jumps were most dangerous. Although our results do not allow us to make any conclusion on the injury risk of these tasks, they do highlight the dependence of knee joint mechanics on type of landing. In other words, the performance of a task during which a lateral jump is required cannot be substituted for, or compared with, that during which a vertical jump is executed. This has implications in injury mechanism research, for example, where the task during which injury typically occurs should be the maneuver examined, whether performed in the laboratory or in the field.

We acknowledge several limitations of the present study. First, the double-leg landing training program was provided over a short period of time. We assumed that the effect of real-time feedback would occur within two training sessions given that lower-limb landing mechanics have been shown to improve following one to three feedback sessions (Onate et al., 2001, 2005; Herman et al., 2009). It is possible, however, that a greater number of sessions are necessary for improvement of frontal-plane knee mechanics and their retention. Given that this was the first study of its kind, our goal was to provide a better understanding of the potential role of real-time quantitative visual feedback on knee mechanics in ACL injury prevention programs. We aimed to establish the ability of such feedback to modify landing knee mechanics prior to addressing the feasibility of implementing a longer feedback training program. We limited the number of training sessions, therefore, to two. Second, although the participants receiving real-time feedback were given instructions on how to reduce their landing knee abduction moments, the concept of joint moments was likely too complex for them to comprehend and thus modify. Perhaps, a parameter that can be visualized, such as a knee joint kinematic variable, may have had a positive effect. Third, markers affixed to the skin were used to calculate joint mechanics, which can be a source of error due to skin motion artifact (Leardini et al., 2005). To minimize this error, we calculated joint mechanics from the 3D trajectories of markers placed over areas without substantial soft tissue movement. Also, Visual 3D software used to compute joint rotations and moments utilize a least squares global optimization technique, which increases the accuracy of the kinematic model defined (Lu & O'Connor, 1999). Finally, the double-leg landing task for which knee mechanics were assessed before and after the double-leg landing training program differed from the task performed during the sessions of the training program. Perhaps, the maximum vertical jump landing represents a maneuver that inherently produces lower knee abduction moments than the drop jump landing. This discrepancy between double-leg landing tasks indicates the possibility that the knee abduction moment threshold set at 75% of peak moment may have been set too high. The two tasks, however, appear to be comparable. The participants receiving real-time feedback achieved a maximum vertical jump height of 32.8 ± 2.1 cm, which is comparable to the height of the platform (31.5 cm) used for the drop jump landings.

Despite several limitations, the present investigation's methods were designed and applied diligently, and thus provide confidence in the results. For example, we ensured good repeatability of marker placement between testing sessions by marking the location of crucial anatomical landmarks during the initial testing session. Doing so allowed us to eliminate variability in marker placement as a contributing factor to the changes in knee mechanics between the pre- and post-training testing sessions. Retention of learning during training was also eliminated as a contributing factor by standardizing the number of days between testing and training sessions for all participants. In addition, a functional method was used to determine the hip joint center – a method proven to be superior to the more common predictive methods that use regression equations (Leardini et al., 1999). This accuracy is critical because poor estimation of joint center location can lead to error in the computation of angles and moments. Lastly, the inclusion of a control group that also participated in an identical double-leg landing training program, but without real-time visual feedback on their knee abduction moment, greatly strengthen this investigation. By including this group, we were able to truly isolate the effect of the real-time feedback from other factors, such as practice and instructions given to the participants.

Perspective

This study revealed that real-time visual feedback on knee abduction moments does not significantly improve frontal-plane knee mechanics during double- and single-leg landing maneuvers. Given the positive effect of real-time feedback in other contexts, in addition to that of delayed verbal/visual feedback and instructions, the investigation of a modified version of our training protocol and its potential for improvement of landing mechanics is recommended. Perhaps, a greater number of training sessions, a different type of real-time feedback (e.g., knowledge of performance), and/or real-time feedback focused on a simpler parameter that can be visualized (e.g., ratio between inter-knee distance and inter-ankle distance) are necessary for improvement to occur and be retained. Results of this investigation also revealed the cross-task transferability of the effect of our landing training program on knee abduction moments from a relatively simple double-leg landing task to a more complex single-leg landing maneuver. It is recommended, therefore, that the cross-task transferability of various ACL injury prevention efforts be investigated, as they may not need to focus on complex tasks during which injury typically occurs. They may focus on simpler tasks that may be incorporated more easily in an injury prevention program.

Key words: biomechanics, knee injury, prevention and control, physical education and training methods.

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