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Landing Instructions Focused on Pelvic and Trunk Lateral Tilt Decrease the Knee Abduction Moment during a Single-leg Drop Vertical Jump

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Declarations:

- **Conflict of interest**: None declared.
- **Ethical approval**: This study was approved by the Institutional Review Board of Hokkaido University (approval number: 17-87).
- **Funding**: None declared.
- **Informed consent**: Written informed consent was obtained from all subjects.

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ABSTRACT

Objectives: To investigate the effects of pelvic and trunk lateral tilt-focused landing instructions on the knee abduction moment during the single-leg drop vertical jump task.

Design: Descriptive laboratory study.

Setting: Motion analysis laboratory.

Participants: Fifteen young, healthy female participants.

Main Outcome Measures: The participants performed 15 single-leg drop vertical jumps. Landing instructions with self-video recordings were provided so that the participants' pelvis and trunk remained horizontal in the frontal plane. Pelvic, trunk and knee kinematics and kinetics were evaluated using a three-dimensional motion analysis system before and after the landing instructions.

Results: The peak knee abduction moment significantly decreased postinstruction (preinstruction 22.6 ± 15.3 Nm, postinstruction 17.9 ± 15.4 Nm, $P = 0.004$), as did pelvic and trunk lateral tilt ($P < 0.01$). The knee abduction and internal rotation angles at initial contact significantly decreased postinstruction ($P = 0.037$, $P = 0.007$), with no significant change in the peak knee abduction and internal rotation angles from pre- to postinstruction.

Conclusions: Landing instructions focused on pelvic and trunk lateral tilt are effective in

decreasing the knee abduction moment during the single-leg drop vertical jump. Pelvic and trunk lateral tilt should be controlled to decrease the knee abduction moment during single-leg landing.

KEYWORDS

Anterior cruciate ligament, Injury prevention, Core, Single-leg landing

1. INTRODUCTION

Anterior cruciate ligament (ACL) injury is one of the most serious sport injuries. It takes 6 to 12 months to return to sport activities after ACL reconstruction, and some athletes who undergo ACL reconstruction give up returning to sports activities (Ardern, Webster, Taylor, & Feller, 2011). Approximately 70% of ACL injuries are observed in noncontact situations, such as jump landing, cutting and pivoting (Agel, Arendt, & Bershadsky, 2005; Boden, Dean, Feagin, & Garrett, 2000). The incidence of ACL injuries is 2 to 8 times higher in female athletes than in male athletes (Agel et al., 2005; Olsen, Myklebust, Engebretsen, & Bahr, 2004). Although ACL injury prevention programs that target female athletes have demonstrated a preventive effect (Kiani, Hellquist, Ahlqvist, Gedeborg, Michaëlsson, & Byberg, 2010; LaBella, Huxford, Grissom, Kim, Peng, & Christoffel, 2011), the incidence of ACL injuries in female athletes remains high (Agel, Rockwood, & Klossner, 2016).

The current ACL injury prevention programs consist of different exercise types but the landing stabilization exercise to ensure proper landing technique and alignment is most effective (Petushek, Sugimoto, Stoolmiller, Smith, & Myer, 2019). Therefore, it is necessary to reveal landing instructions to modify poor landing technique for ACL injury prevention.

Large knee abduction and internal rotation in the small knee flexion during landing have been considered as biomechanical risk factors for ACL injuries and these factors should be improved for ACL injury prevention (Hewett et al., 2005; Kiapour et al., 2016; Koga et al., 2010). In particular, the large knee abduction moment during landing has been considered a major biomechanical risk factor for noncontact ACL injuries in female athletes (Hewett et al., 2005; Levine et al., 2013). Some studies performed with cadaveric landing simulations have suggested that knee abduction moment is one of the major contributing factors to ACL injuries (Bates et al., 2019; Navacchia, Bates, Schilaty, Krych, & Hewett, 2019; Ueno, Navacchia, Bates, Schilaty, Krych, & Hewett, 2020). Therefore, the knee abduction moment during landing should be decreased by preventive training to prevent ACL injuries (Sugimoto, Myer, Foss, & Hewett, 2015).

Landing instructions are commonly used to improve landing biomechanics. Verbal instruction, video feedback, and the combination of verbal instruction and video feedback are used to provide the landing instructions (Dallinga, Benjaminse, Gokeler, Cortes, Otten, & Lemmink, 2017; Milner, Fairbrother, Srivatsan, & Zhang, 2012; Oñate, Guskiewicz, Marshall, Giuliani, Yu, & Garrett, 2005). Verbal instruction or video feedback alone did not decrease the knee abduction moment, during double-leg landing tasks (Dallinga et al., 2017; Milner et al., 2012; Oñate et al., 2005), while the landing instructions using the combination of verbal instruction and video feedback immediately decreased the knee abduction moment during double-leg landing tasks (Herman et al., 2009). Many previous studies have examined landing instructions during double-leg landing, but few have examined landing instructions during single-leg landing, which is one of the situations in which ACL injuries most frequently occur (Krosshaug et al., 2007; Olsen et al., 2004). Landing instructions increase knee flexion angle and decrease ground reaction force during single-leg landing (Cowling, Steele, & McNair, 2003; Elias, Hammill, & Mizner, 2015). However, none have reported the effects of landing instructions on the knee abduction moment during single-leg landing. Previous studies have reported that the knee abduction moment is larger during single-leg landing than during double-leg landing (Wang, 2011; Yeow, Lee, & Goh, 2011). In addition, the knee abduction moment during single-leg landing is not correlated with the knee abduction moment during double-leg landing (Taylor, Ford, Nguyen, & Shultz, 2016). Therefore, it is unknown whether landing instructions decrease the knee abduction moment during single-leg landing.

The trunk motions in the frontal plane have been considered to influence knee abduction moment. A previous study showed that there is a significant correlation between the peak knee abduction moment and trunk lateral tilt angle at initial contact (IC) during single-leg landing (Dempsey, Elliott, Munro, Steele, & Lloyd, 2012). Other studies have reported that a larger trunk lateral tilt toward the stance leg increases the peak knee abduction moment during side-step cutting (Dempsey, Lloyd, Elliott, Steele, Munro, & Russo, 2007; Jamison, Pan, & Chaudhari, 2012). In addition, the increase in intended trunk lateral tilt or rotation during landing increased the knee abduction and internal rotation angles and moments (Critchley et al., 2020; Hinshaw, Davis, Layer, Wilson, Zhu, & Dai, 2019; Saito, Okada, Sasaki, & Wakasa, 2020). However, the effects of the landing instruction to decrease trunk lateral motion on knee kinematics were unclear. Pelvic lateral tilt has also been shown to influence the frontal-plane knee moment during single-leg standing and gait (Dunphy, Casey, Lomond, & Rutherford, 2016; Takacs & Hunt, 2012). However, pelvic lateral tilt and its effect on knee abduction moment in jump-landing training have not been studied (Dempsey, Elliott, Munro, Steele, Lloyd, 2014; Neilson, Ward, Hume, Lewis, & McDaid, 2019). According to previous research, controlling pelvic lateral tilt as well as trunk lateral tilt can decrease the knee abduction moment during single-leg landing.

The primary purpose of the present study was to investigate the effects of landing instructions focused on pelvic and trunk lateral tilt on the knee abduction moment during single-leg landing in female participants. In addition, the second purpose was to investigate the effects of the landing instructions on the knee abduction angle, flexion and internal rotation angles and moments during single-leg landing because these variables are also considered as biomechanical risk factors for ACL injuries (Hewett et al., 2005; Kiapour et al., 2016; Koga et al., 2010) . The hypotheses were that the pelvic and trunk lateral tilt angles decrease after the landing instructions are provided and that, consequently, the knee abduction moment also decreases.

2. METHODS

2.1. Participants

Fifteen female participants (mean ± SD: age 20.7 ± 0.7 years; height 160.8 ± 5.2 cm; weight 54.7 ± 5.9 kg) participated in this study. A priori power analysis in a pilot study using 6 participants showed that 15 participants were required to achieve a statistical power of 0.8 with an alpha level of 0.05 and an effect size of 0.8. All participants had experience with regular sports activities (4 basketball, 2 volleyball, 2 badminton, 4 tennis, 2 track and field, 1 dancing) that were defined as sports activities for 30 minutes a day at least 3 times per week (Schmitz, Kulas, Perrin, Riemann, & Shultz, 2007). Exclusion criteria were a history of musculoskeletal injuries within the last 6 months, surgeries or fractures of the lower extremities or trunk. None of the participants met any of the exclusion criteria. All participants read and signed informed consent forms prior to their inclusion in this study. This research was approved by the institutional review board of our university (approval number: 17-87).

2.2. Procedures

The experimental procedure is displayed in Fig. 1. The participants performed a warm-up on a stationary bicycle for 5 minutes. Next, data were collected during a static standing trial for each participant. A single-leg drop vertical jump (SDVJ) was used for the practice session as well as for the before-after landing instructions (Fig. 2). The SDVJ was selected because the combination of the trunk lateral tilt angle and knee abduction angle displayed during this task has been reported to be a significant predictor of noncontact knee injuries, including ACL tears (Dingenen et al., 2015). All participants were barefoot to exclude the effects of shoes on lower extremity kinematics and kinetics (Hong, Yoon, Kim, & Shin, 2014). The dominant leg (the side used for kicking a ball), which was the right leg in all participants, was then assessed. Each participant stood on a 30-cm-tall box on their dominant leg, then dropped from the box, and landed with their dominant leg on a force plate. They then performed a maximum vertical jump immediately after landing. The participants were asked to look forward and to keep their elbows and hands up to ear level to avoid marker occlusion throughout the SDVJ task (Dingenen et al., 2015; Ishida et al., 2015). Trials in which the nondominant leg touched the ground or the participant lost balance during the test were defined as failed trials and were excluded from the analysis.

The landing instruction protocol and the number of practice trials were determined on the basis of a previous study (Oñate et al., 2005). The participants were allowed to rest between each trial and session, as needed. After a static standing trial was collected, the preinstruction test consisting of 3 SDVJ trials was conducted (Fig. 1). During the preinstruction test, the trials were recorded using a digital video camera (DCR-TRV900 NTSC, SONY, Tokyo, Japan) placed in a frontal plane view of the landing zone. After the preinstruction test, the participants were instructed to land “keeping the trunk vertical and pelvis horizontal without tilting in the frontal plane” by checking their preinstruction test videos. The video of each trial was shown twice - the first time at normal speed and the second one at a slower speed. Then 3 practice sessions were provided with each session including 5 SDVJ trials. The trials were recorded using the digital video camera during practice sessions, as in the preinstruction test. Between the sessions, the same “keep the trunk vertical and pelvis horizontal without tilting in the frontal plane” landing instructions were provided while showing the videos of their previous sessions. Landing instructions were not individualized to each participant. After the practice sessions followed by the landing instructions, postinstruction tests consisting of 3 SDVJ trials were conducted.

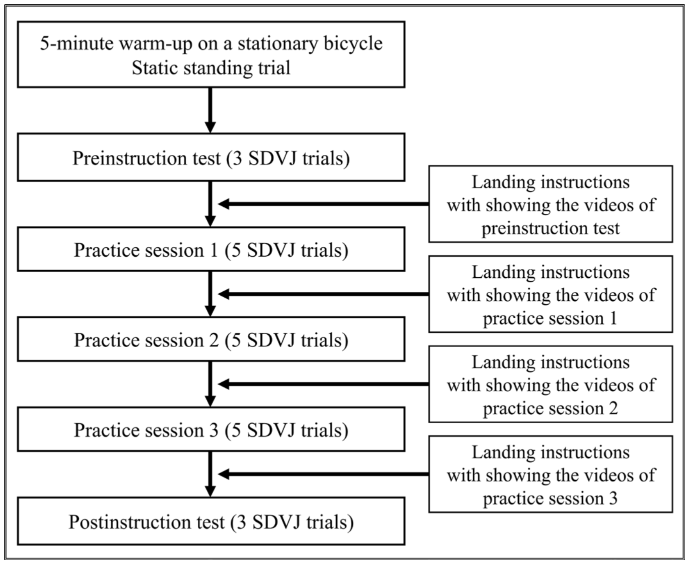

Fig. 1. Experimental procedure

SDVJ indicates a single-leg drop vertical jump task.

Fig. 2. Single-leg drop vertical jump (SDVJ) task

Participants dropped from a 30-cm-tall box with one leg and then performed a maximum vertical jump on the same leg.

2.3. Data collection

All data were collected with Cortex 5.0.1 (Motion Analysis Corporation, Santa Rosa, CA, USA), a motion analysis system with seven high-speed cameras (Hawk cameras; Motion Analysis Corporation), and a force plate (Type 9286, Kistler AG, Winterthur, Switzerland). The sampling rates were set to be 200 Hz for the marker coordinate data and 1,000 Hz for the force plate data. Retroreflective markers were placed on the sacrum, right iliac crest, and both acromions, anterosuperior iliac spines (ASIS), greater trochanters, medial and lateral femoral condyles, medial and lateral malleoli, heels, and second and fifth metatarsal heads, and cluster markers were placed on the thigh and shank of the dominant leg (Ishida et al., 2015).

2.4. Data analysis

The marker coordinate data and force plate data were low-pass filtered using a zero-lag fourth-order Butterworth filter at 12 Hz. The knee joint angles and moments were calculated with SIMM 6.0.2 software (MusculoGraphics, Santa Rosa, CA, USA) using inverse kinematics and inverse dynamics, respectively, in a rigid-body dynamics pipeline. Each participant's anthropometric model was created based on the static trial and the premeasured foot length and width. The segment inertia properties were adjusted based on each participant's body mass and segment lengths (de Leva, 1996). The segment coordinate system was located such that the pelvis was at the midpoint of the right and left ASIS markers, the femur was at the center of the femoral head, the tibia was at the midpoint between the femoral medial and lateral condyles, and the tibia coordinate system was fixed in the tibia (Delp, 1990). The pelvic and trunk lateral tilt were calculated as the frontal plane projection angle with respect to the global coordinate system by using MATLAB (MathWorks, Natick, Massachusetts, USA). The trunk lateral tilt angle was defined as the angle between the line connecting the left shoulder marker and the left ASIS marker and a vertical line, and positive values corresponded to tilting toward the support-leg side (DiCesare, Bates, Myer, & Hewett, 2014). The pelvic lateral tilt angle was defined as the angle between the line connecting both ASIS markers and a horizontal line, and positive values corresponded to pelvic elevation on the contralateral-leg side (Fig. 3). All angles measured during the static standing trial were set to 0°.

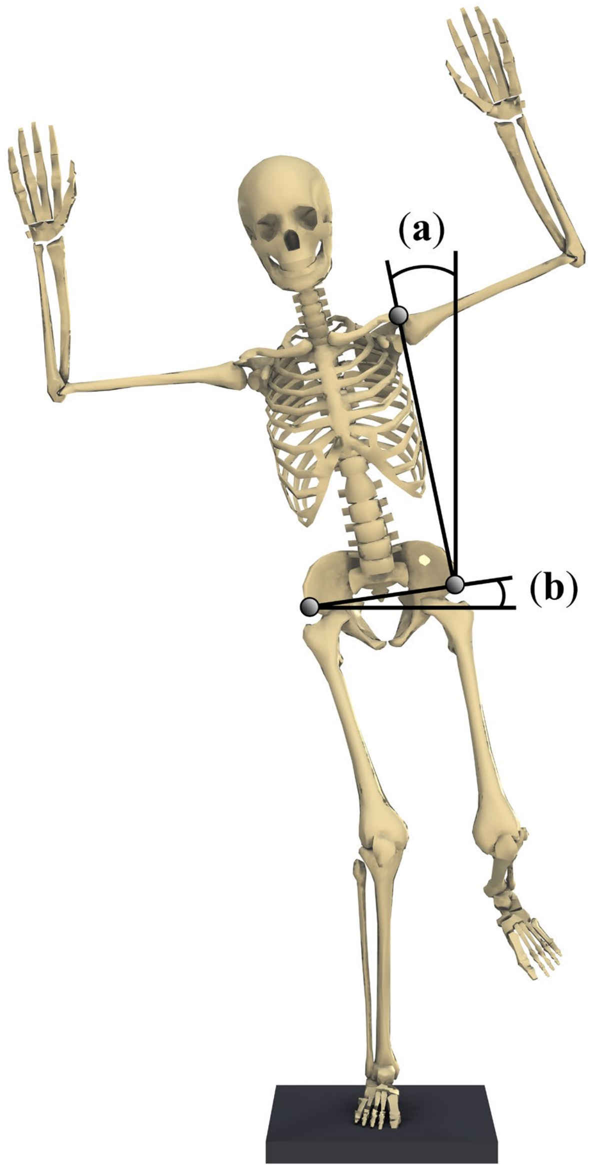

Fig. 3. The trunk and pelvic lateral tilt angles. (a) The trunk lateral tilt angle was defined as the angle between the line connecting the left shoulder marker and the left ASIS marker and a vertical line. (b) The pelvic lateral tilt angle was defined as the angle between the line connecting the right and left ASIS markers and a horizontal line.

IC was defined as when the vertical ground reaction force first exceeded 10 N, and toe-off (TO) was defined as when the vertical ground reaction force first fell below 10 N after IC (Ford, Myer, & Hewett, 2007). The landing phase was defined as the period from IC to peak knee flexion during the first landing. The peak knee abduction, flexion and internal rotation moments and peak ground reaction force during the landing phase were computed. The pelvic and trunk lateral tilt and knee abduction, flexion and internal rotation angles were calculated at IC and when the peak angle was attained during the landing phase. In addition, the jump height and the stance time were calculated to assess the potential effect of the landing instructions on performance (Dai, Garrett, Gross, Padua, Queen, & Yu, 2015). The jump height was calculated by subtracting the height of the sacrum marker in the static standing trial from the maximal height of the sacrum marker after TO. The stance time was calculated as the duration of stance phase from IC to TO. The mean of three trials for each of the pre- and postinstruction tests was used for statistical analysis.

2.5. Statistical analysis

Paired t-tests were performed to determine the effects of instructions on the kinematic, kinetic and jump performance data. Pearson's correlation coefficients were used to determine the association between the change in peak knee abduction moment from pre- to postinstruction and the changes in pelvic and trunk lateral tilt angle from pre- to postinstruction. All statistical analyses were performed using IBM SPSS Statistics, version 22 (IBM, Armonk, NY, USA). The level of significance was set to be $P < 0.05$. In addition, effect sizes were calculated for all outcomes with Cohen's *d* using G*Power 3.1. (Institute of Experimental Psychology, Heinrich Heine University, Dusseldorf, Germany). The effect sizes were interpreted as follows: 0.80 indicated a large effect, 0.50 indicated a medium effect, and 0.20 indicated a small effect (Cohen, 1988).

3. RESULTS

All participants presented the pelvic and trunk lateral tilt angle at IC and peak during the preinstruction test. The landing instructions significantly decreased the pelvic lateral tilt angle at IC, with a large effect size ($P = 0.002$, $d = 1.00$, Fig. 4a). The peak pelvic lateral tilt angle also decreased from pre- to postinstruction, with a large effect size ($P = 0.001$, $d = 1.06$, Fig. 4a). After receiving the instructions, 13/15 (87%) of the participants had a decreased pelvic lateral tilt angle at IC and a decreased peak pelvic lateral tilt angle.

Additionally, the landing instructions significantly decreased the trunk lateral tilt angle at IC, with a large effect size ($P < 0.001$, $d = 1.49$, Fig. 4b). The peak trunk lateral tilt angle also decreased from pre- to postinstruction, with a large effect size ($P < 0.001$, $d = 1.66$, Fig. 4b). After receiving the instructions, 15/15 (100%) of the participants demonstrated decreases in the trunk lateral tilt angle at IC and the peak trunk lateral tilt angle.

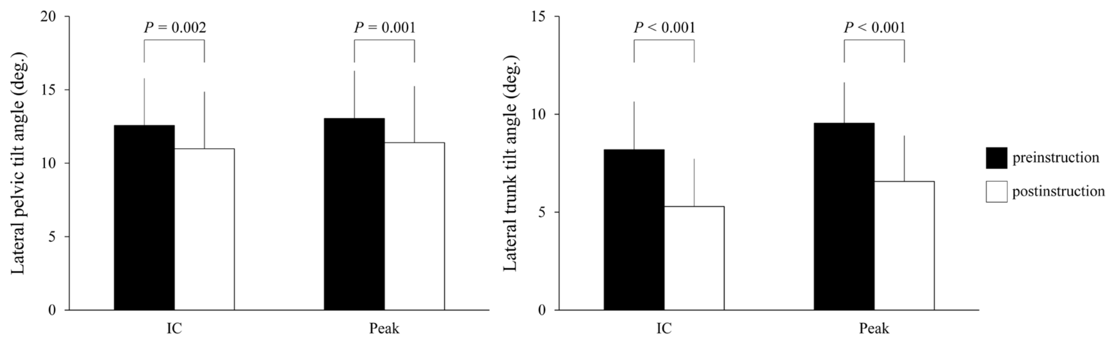

Fig. 4. The pelvic (a) and trunk (b) lateral tilt angles recorded before and after the landing instructions focused on pelvic and trunk lateral tilt. The error bars indicate standard deviations. IC: initial contact

All participants demonstrated the knee abduction moment during the preinstruction test. The peak knee abduction moment significantly decreased from pre- to postinstruction, with a large effect size (*P* = 0.004, *d* = 1.31, Fig. 5, Table 1). After receiving the instructions, 14/15 (93%) of the participants demonstrated decreases in the peak knee abduction moment. There were no significant correlations between the change in the peak knee abduction moment from pre- to postinstruction and the changes in the pelvic and trunk lateral tilt angles at IC from pre- to postinstruction (pelvic tilt: *P* = 0.564, *R* = -0.162; trunk tilt: *P* = 0.253, *R* = -0.315). Additionally, there were no significant correlations between the change in the peak knee abduction moment from pre- to postinstruction and the changes in the peak pelvic and trunk lateral tilt angles from pre- to postinstruction (pelvic tilt: *P* = 0.857, *R* = -0.051; trunk tilt: *P* = 0.401, *R* = -0.234). There were no significant differences in the peak knee flexion and internal rotation moments and the peak vertical ground reaction force (Table 1).

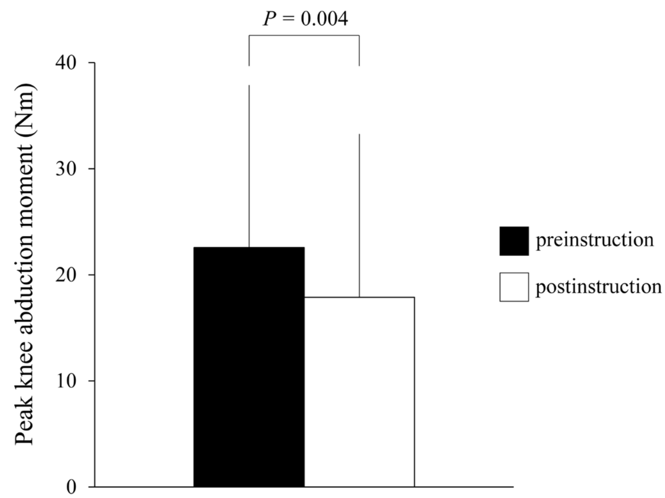

Fig. 5. The peak knee abduction moment recorded before and after the landing instructions focused on pelvic and trunk lateral tilt. The error bars indicate standard deviations.

Table 1. Comparison of external knee joint moments and vertical ground reaction force between the tests performed before and after landing instructions focused on pelvic and trunk lateral tilt.

	preinstruction	postinstruction	*P* value
Peak external moment (Nm)			
knee flexion moment	142.9 ± 38.4	143.7 ± 30.3	0.815
knee abduction moment	22.6 ± 15.3	17.9 ± 15.4	**0.004**
knee internal rotation moment	27.3 ± 18.7	28.8 ± 19.7	0.468
Peak vertical ground reaction force (N)	2356.6 ± 400.3	2337.9 ± 448.5	0.402

The data are presented as the mean ± SD.

The knee abduction and internal rotation angles at IC significantly decreased postinstruction, with medium and large effect sizes (P = 0.037, d = 0.78; P = 0.007, d = 0.82), while there were no significant differences in the peak knee abduction and internal rotation angles (Table 2). For the knee flexion, there were no significant changes from pre- to postinstruction (Table 2). The jump height significantly decreased from pre- to postinstruction, with a large effect size (P = 0.004, d = 0.88), while the stance time did not change (Table 3).

Table 2. Comparison of knee kinematics between the tests performed before and after landing instructions focused on pelvic and trunk lateral tilt.

	preinstruction	postinstruction	*P* value
Knee flexion angle (deg.)			
at IC	17.3 ± 5.4	16.8 ± 5.5	0.641
peak angle	60.6 ± 6.6	61.9 ± 5.5	0.423
Knee abduction angle (deg.)			
at IC	0.9 ± 2.1	0.3 ± 2.0	**0.037**
peak angle	9.2 ± 5.9	8.5 ± 5.9	0.163
Knee internal rotation angle (deg.)			
at IC	1.1 ± 6.7	-0.3 ± 7.1	**0.007**
peak angle	11.4 ± 7.6	11.0 ± 7.5	0.362

IC: initial contact

The data are presented as the mean ± SD.

Table 3. Comparison of the jump performance between the tests performed before and after landing instructions focused on pelvic and trunk lateral tilt.

	preinstruction	postinstruction	*P* value
Jump height (mm)	196.9 ± 20.0	182.5 ± 22.5	**0.004**
Stance time (ms)	318.4 ± 40.0	323.9 ± 39.3	0.370

The data are presented as the mean ± SD.

4. DISCUSSION

The primary purpose of this study was to determine the effects of landing instructions to keep the pelvis horizontal and the trunk vertical in the frontal plane on the knee abduction moment during the SDVJ task. The most important findings were that the landing instructions significantly decreased the peak knee abduction moment as well as the pelvic and trunk lateral tilt angles during the SDVJ. However, the knee flexion angle and vertical ground reaction force did not change from pre- to postinstruction. These findings supported our hypothesis that the knee abduction moment also decreases by decreasing the pelvic and trunk lateral tilt angles after the landing instructions.

In the present study, the expected changes in the frontal-plane pelvic and trunk kinematics were observed postinstruction. Therefore, the protocol for the landing instructions and the content of the landing instructions (i.e., to keep the trunk vertical and pelvis horizontal without tilting them in the frontal plane) is valid. Providing landing instructions and short practice sessions is an effective method for reducing pelvic and trunk lateral tilt during the SDVJ.

The peak knee abduction moment significantly decreased postinstruction compared with preinstruction. This is the first study to report that landing instructions decrease the peak knee abduction moment during the single-leg landing task. This finding is consistent with those from previous studies that have reported that the increase in trunk lateral tilt or rotation increase the knee abduction moment during landing (Critchley et al., 2020; Dempsey et al., 2012). A previous study on cutting maneuvers reported results that are consistent with those in the present study (Dempsey, Lloyd, Elliott, Steele, & Munro, 2009). It has been suggested that the knee abduction moment during single-leg stance is affected by the center of mass (COM) position relative to the knee (Celebrini, Eng, Miller, Ekegren, Johnston, & MacIntyre, 2012). When the pelvic and trunk lateral tilt angles decrease during single-leg support, the COM moves toward the medial side of the stance leg (Takacs & Hunt, 2012). Then, the moment arm for knee abduction is shortened. This concept is assumed to be the mechanism by which knee abduction moment decreased in the present study. The present findings suggested that the landing instructions focused on pelvic and trunk lateral tilt decreased the peak knee abduction moment by decreasing the pelvic and trunk lateral tilt angles.

It was expected that the larger the decreases in the pelvic and trunk lateral tilt angles were, the larger the decrease in the peak knee abduction moment from pre- to postinstruction. However, there were no significant correlations between the change in the peak knee abduction moment and the changes in the pelvic and trunk lateral tilt angles in the present study. All participants demonstrated decreases in the trunk lateral tilt angle, but some did not demonstrate decreases in the peak knee abduction moment or pelvic lateral tilt angle. In this study, the landing instructions decreased the peak knee abduction moment by decreasing the pelvic and trunk lateral tilt angles, but the magnitude of the effects of decreased pelvic and trunk lateral tilt angle may have differed among participants. Therefore, the linear relationships between the change in the peak knee abduction moment and the changes in the pelvic and trunk lateral tilt angles may not have been detected. The effects of other factors that were correlated with the knee abduction moment during single-leg landing (e.g., trunk rotation, knee flexion and rotation and foot rotation) should be investigated in the future (Dempsey et al., 2012).

In a previous study, a 6-week landing training program did not decrease the peak knee abduction moment during the single-leg landing with ball catching (Dempsey et al., 2014). In that study, although the landing instructions were focused on increasing knee flexion, reducing trunk lateral tilt and reducing trunk rotation, a significant change was found only in knee flexion, which increased. Therefore, it may have been difficult for participants to focus on knee and trunk motions while catching a ball. The present study showed that simple instructions to keep the pelvis and trunk positioned horizontally decreased the peak knee abduction moment. Future studies should be conducted to investigate the effects of simple landing instructions focused on pelvic and trunk lateral tilt on the knee abduction moment during single-leg landings in game-like situations.

Decreases in knee abduction moment are very important for ACL injury prevention. In a cadaver study, combined external loads of knee abduction moment, internal tibial rotation moment, and anterior tibial shear force under axial impact produced clinically relevant ACL injuries, and only knee abduction moment significantly contributed to peak ACL strain at injuries (Levine et al., 2013). Excessive knee abduction moment is considered a contributing factor of ACL injuries. (Bates et al., 2019; Navacchia et al., 2019; Ueno et al., 2020). Therefore, landing instructions focused on pelvic lateral tilt as well as trunk lateral tilt should be given to decrease the knee abduction moment during single-leg landing.

A previous study reported that the trunk lateral tilt angle during the SDVJ task was one of the significant predictors of noncontact knee injuries, including ACL tears (Dingenen et al., 2015). A video analysis study of ACL injuries during single-leg movements showed that the trunk lateral tilt angles of ACL-injured female athletes were larger than those of control female athletes (Hewett, Torg, & Boden, 2009). There was a significant association between a large pelvic lateral tilt angle and ACL injury risk in female athletes (Leppänen et al., 2020). The present study showed that landing instructions are effective in reducing pelvic and trunk lateral tilt. Therefore, landing instructions focused on pelvic lateral tilt as well as trunk lateral trunk lean should be incorporated into ACL injury prevention training programs. In prevention programs that have recently been shown to be successful, landing instructions about controlling not only the knee position but also the trunk position have been given (Omi et al., 2018).

The findings regarding the knee abduction angle at IC after landing instructions are consistent with those from previous studies that have reported that the increase in intended trunk lateral tilt or rotation increases the knee abduction angle at IC or at the early landing phase (Critchley et al., 2020; Hinshaw et al., 2019). As a result of the decrease in the knee abduction moment, the knee abduction angle was also expected to decrease. However, the results of this study did not reveal a change in the peak knee abduction angle, unlike the findings of a previous study, which reported that the increase in intended trunk lateral tilt increases the peak knee abduction angle (Saito et al., 2020). The peak knee abduction angle may be increased by factors other than the external knee abduction moment. A previous study suggested that knee abduction motion during the double-leg drop vertical jump is high to prepare the individual for the subsequent jump after landing (Ishida et al., 2018). An alternative intervention other than providing landing instructions focused on pelvic and trunk lateral tilt should be developed to decrease the knee abduction angle during the SDVJ.

The findings regarding the decreased knee internal rotation angle at IC after the landing instructions in the present study supported the results from previous studies on the effects of intended trunk lateral tilt (Hinshaw et al., 2019). The peak knee internal rotation angle and moment did not change from pre- to postinstruction in the present study. The increase in intended trunk rotation increased the peak knee internal rotation angle and moment (Critchley et al., 2020). Adding landing instructions focused on pelvic and trunk rotation may help to decrease the internal rotation angle and moment during landing.

The results in this study showed that the knee flexion angle and moment and vertical ground reaction force did not change from pre- to postinstruction. In previous studies, landing instructions provided to increase knee flexion and to decrease the impact of landing have demonstrated the intended effects during single-leg landing (Cowling et al., 2003; Elias et al., 2015). The landing instructions were “land with your knee bent” or "land as softly and quietly as possible" in the previous studies. The landing instructions focused only on the pelvic and trunk lateral tilt did not change the knee flexion angle and moment or the vertical ground reaction force in this study. The instructions that address modifications for pelvic and trunk lateral tilt, knee flexion and landing impact may improve both the knee abduction moment and vertical ground reaction force. However, the combined effects of these instructions have not been reported, and future research is warranted.

The results of this study showed that the stance time did not change, while the jump height significantly decreased after receiving the instructions. A previous study also reported performance deterioration with the immediate modification of landing techniques, as found in the present study (Dai et al., 2015). In previous studies, 6-week ACL injury prevention programs improved ACL injury biomechanical risks and performance at the same time (Chappell & Limpisvasti, 2008; Myer, Ford, Palumbo, & Hewett, 2005). A certain period of training may be needed to improve landing techniques while maintaining jump performance.

This study had some limitations. First, the present study tested only the immediate effect of landing instructions. Therefore, additional studies are needed to assess the retention and transfer of these effects to actual sports activities. Second, the present study included only female participants. A previous study showed that the trunk lateral tilt angle of male participants was smaller than that of female participants during the single-leg squat task (Nakagawa, Moriya, Maciel, & Serrão, 2012). The landing instructions used in this study may be less effective in male participants than in female participants.

5. CONCLUSION

The present study showed that landing instructions focused on pelvic and trunk lateral tilt decrease the peak knee abduction moment as well as the pelvic and trunk lateral tilt angles during single-leg landing. These findings indicate that the control of the pelvis and trunk should be emphasized to decrease the knee abduction moment during single-leg landing.

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