Original Research

Effect of Heading a Soccer Ball as an External Focus During a Drop Vertical Jump Task

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Investigation was performed at the Osaka University of Health and Sport Sciences, Osaka, Japan

Background: Research has demonstrated that performing a secondary task during a drop vertical jump (DVJ) may affect landing kinetics and kinematics.

Purpose: To examine the differences in the trunk and lower extremity biomechanics associated with anterior cruciate ligament (ACL) injury risk factors between a standard DVJ and a DVJ while heading a soccer ball (header DVJ).

Study Design: Descriptive laboratory study.

Methods: Participants comprised 24 college-level soccer players (18 female and 6 male; mean ± SD age, 20.04 ± 1.12 years; height, 165.75 ± 7.25 cm; weight, 60.95 ± 8.47 kg). Each participant completed a standard DVJ and a header DVJ, and biomechanics were recorded using an electromagnetic tracking system and force plate. The difference (Δ) in 3-dimensional trunk, hip, knee, and ankle biomechanics between the tasks was analyzed. In addition, for each biomechanical variable, the correlation between the data from the 2 tasks was calculated.

Results: Compared to the standard DVJ, performing the header DVJ led to significantly reduced peak knee flexion angle ($\Delta = 5.35°$; $P = .002$), knee flexion displacement ($\Delta = 3.89°$; $P = .015$), hip flexion angle at initial contact ($\Delta = -2.84°$; $P = .001$), peak trunk flexion angle ($\Delta = 13.11°$; $P = .006$), and center of mass vertical displacement ($\Delta = -0.02$m; $P = .010$), and increased peak anterior tibial shear force ($\Delta = -0.72$ N/kg; $P = .020$), trunk lateral flexion angle at initial contact ($\Delta = 1.55°$; $P < .0001$), peak trunk lateral flexion angle ($\Delta = 1.34°$; $P = .003$), knee joint stiffness ($\Delta = 0.002$ N*m/kg/deg; $P = .017$), and leg stiffness ($\Delta = 8.46$ N/kg/m; $P = .046$) compared to those in standard DVJs. In addition, individuals' data for these variables were highly and positively correlated between conditions ($r = 0.632$-0.908; $P < .001$).

Conclusion: The header DVJ task showed kinetic and kinematic parameters that suggested increased risk of ACL injury as compared with the standard DVJ task.

Clinical Relevance: Athletes may benefit from acquiring the ability to safely perform header DVJs to prevent ACL injury. To simulate real-time competition situations, coaches and athletic trainers should incorporate such dual tasks in ACL injury prevention programs.

Keywords: ACL injury; football (soccer); landing biomechanics; dual-task performance

Soccer is the most popular sport in the world, and its popularity is still growing.[36] Anterior cruciate ligament (ACL) rupture is among the most severe injuries in soccer, and its incidence rate is among the highest of all sports.[11] Most ACL injuries are noncontact injuries; in both sexes, landing from a jump is a common ACL injury mechanism.[7,52] An ACL injury not only leads to short- and long-term health complications, such as a loss of sport time and increased risk of knee osteoarthritis,[30,33,35,57] but can also negatively affect the success of the team.[31] Therefore, eliminating and modifying ACL injury risk factors is essential for primary ACL injury prevention.

Recent global research on noncontact ACL injuries in athletes has identified numerous biomechanical risk factors: decreased joint flexion in the sagittal plane of the ankle, knee, hip, and trunk, as well as increased knee internal rotation angles, knee abduction angles and moments, anterior tibial shear force (ATSF), trunk lateral bending, and peak ground-reaction forces (GRFs).[‖] Another critical ACL injury risk factor is the implementation of a secondary task during sharp decelerating motions.[21] Indeed, when ACL injuries occur in real-world performance, the athlete is often simultaneously directing attention toward opponents, balls, goals, and tasks, thus performing dual-task motions[25,39] (ie, the simultaneous performance of 2

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individual tasks[43]). Previous studies have shown that the imposition of a secondary task that requires attention can negatively affect landing mechanics, with increased ACL loading.[2,10,15,34] Ford et al[15] found that adding a secondary task of grabbing a ball at the apex of a participant's jump during a drop vertical jump (DVJ) task increased the maximum knee extension moment. Additionally, Dai et al[10] demonstrated that the inclusion of a secondary task of counting backward during a DVJ task resulted in decreased knee flexion angles at initial contact (IC) and increased peak posterior and vertical GRFs. Mok et al[34] reported that adding a horizontal bar, as an overhead target, to a DVJ task decreased the peak knee flexion angle and range of knee flexion and increased the peak vertical GRF. Furthermore, Almonroeder et al[2] reported that the inclusion of a secondary task of grabbing a ball at the maximum height of a participant's vertical jump during a DVJ task resulted in higher peak GRFs, lower peak knee flexion angles, and greater peak knee abduction angles. Therefore, dual-task performance during sharp decelerating motions may increase the chance of harmful knee loadings and the risk of ACL injury.[2,10,15,34]

Because abnormal knee motions and loadings during landing have been shown to be associated with ACL injury risk,[7,11,19,49-51] the DVJ task is widely used as a screening method for ACL injury risk.[3,16,18,29,40,55] One way to investigate the effectiveness of the evaluation of DVJ landings is to determine whether controlled DVJ landings are associated with those close to real-world situations. ACL injuries often occur when athletes perform dual tasks during sharp decelerating motions.[25,39] As such, if the kinetic and kinematic parameters associated with ACL injury risk are assessed during a DVJ and found to be magnified during DVJ with a secondary task, we can assume that evaluating controlled DVJ landings are an effective way to identify athletes at risk.

In soccer, landing in a heading situation is one of the most common playing situations associated with noncontact ACL injury and is a typical dual-task condition.[14,58] In this study, we evaluated ACL injury risk–associated kinetic and kinematic parameters during a standard DVJ and a DVJ while heading a soccer ball (header DVJ) and examined the differences in trunk and lower extremity biomechanics between the tasks. We hypothesized that soccer players with a higher ACL injury risk profile under standard DVJ conditions would also have a higher ACL injury risk profile under header DVJ conditions and vice versa but the biomechanical parameters associated with ACL injury risk would be significantly magnified during header DVJs.

METHODS

Participants

The protocol for this study received ethics committee approval, and the study participants were aware of the potential benefits and risks of the investigation before signing an institutionally approved informed consent document. A total of 24 college-level soccer players participated in this study (18 female and 6 male; mean ± SD age, 20.04 ± 1.12 years; height, 165.75 ± 7.25 cm; weight, 60.95 ± 8.47 kg). None of the participants had lower extremity ligamentous injuries or pain in either limb at the time of participation.

For all participants, we recorded demographic and anthropometric data, including age, height, mass, and soccer experience. Participants visited the sports performance laboratory at our institution for 1 testing session, where they performed a standard DVJ (a landing task with a subsequent jump) as well as a header DVJ. The secondary task of heading a soccer ball divides the participant's attention during performance of the DVJ, resulting in a dual-task condition that closely mirrors the demands of soccer. The participants performed all DVJ tasks while wearing the same running shoe type and short spandex shirt.

Standard DVJ

Participants performed the double-leg DVJ task similar to that previously described for the Landing Error Scoring System.[41] Participants jumped from a box 30 cm in height to a distance at 50% of their height, away from the front edge of the force plates, and immediately rebounded for a maximum vertical jump on landing (Figure 1A). During task instruction, emphasis was placed on the participants jumping as high as they could on landing from the box while swinging their arms freely. Participants were not provided any feedback or coaching on their landing technique unless they were performing the task incorrectly. After task instruction, the participant was given as many practice trials as needed (typically 2) to become comfortable with the task. A successful jump was characterized by the following criteria: (1) jumped off the box with both feet; (2) jumped forward but not vertically to reach the 2 force plates below; (3) landed with 1 foot on each force plate; (4) completed the task in a fluid motion; and (5) held the position for 5 seconds after landing, with head and shoulders facing forward.

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Ethical approval for this study was obtained from Osaka University of Health and Sport Sciences (No. 29-3).

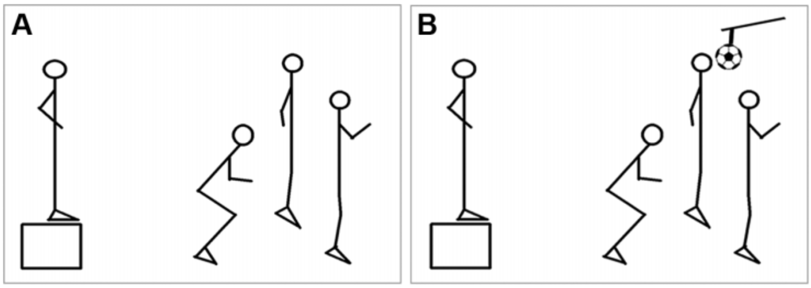

Figure 1. (A) Standard drop vertical jump task. Participants jumped from a box with a height of 30 cm onto a force plate at a distance of 50% of their height, immediately rebounded for a maximum vertical jump on landing, and landed back on the force plate. (B) Drop vertical jump while heading a soccer ball: participants jumped from a box with a height of 30 cm onto a force plate at a distance of 50% of their height, immediately rebounded for a maximum vertical jump on landing, headed the center of the soccer ball (height of the soccer ball was adjusted to each participant's forehead height based on his or her maximum jumping performance), and landed back on the force plate.

Header DVJ

For this condition, a soccer ball was attached to the ceiling of the laboratory by means of a string, and participants were asked to jump from the box, land, jump up as quickly as possible, head the center of the soccer ball, and land back on the force plate (Figure 1B). For each participant, the ball was adjusted to a height such that it was aligned with his or her forehead after a vertical jump from the ground. The ball was then kept stationary at that height, and after some trials of the header DVJ task, the exact height of the ball for the header condition for that participant was determined. We ensured that the height of the ball was adjusted to each participant based on his or her maximum jumping performance.

After task instruction and practice trials, participants performed 3 successful trials of each DVJ condition. All tasks were supervised by one of the researchers (H.A.) to ensure that the participants performed the tasks correctly. Before performing the tasks, the participants warmed up with 10 repetitions of a 2-leg squat with toe rise. Sufficient rest, as determined by the participant, was provided between trials so that they were not tired when performing the trials; if a participant felt tired, the rest period between the trials was increased.

Biomechanical Instrumentation and Digitization Procedures

A nonconductive force plate (4060; Bertec) and 3-dimensional (3D) electromagnetic motion-tracking system (Ascension Star Hardware, Ascension Technology; Motion Monitor Software, Innovative Sports Training) were used to obtain 3D kinetic and kinematic data at 1400 and 140 Hz, respectively. Motion sensors were attached directly to the skin above the dorsum of the foot, tibial shaft, iliotibial band on the lateral aspect of the thigh, and sacrum using double-sided tape and secured with athletic underwrap and white tape.[50] For the foot dorsum, participants removed their socks, attached the sensors to the dorsal surfaces of their feet, replaced their shoes, and fastened their shoelaces to secure the sensors.[50] A sensor was also attached to the posterior aspect of the thorax using a manufacturer-made bracket and secured using an elastic bandage.

Thereafter, the participants' legs, sacra, and trunks were digitized and their joint centers estimated as previously reported.[50] The motion sensors of the motion-tracking system attached to each segment had their own fixed orthogonal axes. The sensors recognized their 3D position and orientation relative to the electromagnetic transmitter, which transmitted an electromagnetic field with 3D coordinates to create the laboratory coordinate system. The motion-tracking system recognized the relative positions of the landmarks of the body relative to the motion sensors attached to each segment to calculate the joint centers and construct the segment coordinate systems. The world coordinate system—with the x-axis anteroposterior (AP), with forward as the positive direction; the y-axis vertical, with upward as the positive direction; and the z-axis lateral, with medial to lateral as the positive direction—was embedded in the center of the 2 force plates.

Ankle and knee joint centers were defined as the midpoints between the lateral and medial malleoli and between the lateral and medial femoral epicondyles, respectively. The hip joint center was defined by calculating the center of the best sphere described by the trajectory of motion sensors placed on the thigh during 5 hip rotational positions.[26] The longitudinal axes of the thorax, thigh, shank, and foot segment coordinate systems were aligned with lines connecting the C7 and T12 spinous processes, hip and knee joint centers, knee and ankle joint centers, and ankle joint center and tip of the second toe, respectively.

The participant stood straight and faced straight toward the positive direction of the x-axis with feet aligned parallel and a shoulder-width apart. In this position, the AP axes of segments that cross at a right angle to the longitudinal axis were aligned to the x-axis of the world coordinate system. For the sacrum, the AP axis was initially aligned to the x-axis of the world coordinate system in the same standing position; subsequently, the longitudinal axis was constructed so that it crossed at a right angle to the AP axis.

The lateral axes of each segment were then aligned perpendicular to the longitudinal segmental and AP axes. The longitudinal axis, AP axis, and lateral axes of the thigh and shank were assigned as x, y, and z, respectively, while those for the foot were assigned as y, x, and z, respectively. The origins of each segment coordinate system were embedded at the segmental center-of-mass positions.

Euler angles were used to calculate segment relative angles with the rotational sequence z-y-x. Trunk angles were defined as the thorax angles relative to the world coordinate system. Hip, knee, and ankle joint angles were defined as the relative angles of the distal segment to the adjacent proximal segments. Net internal joint moments produced by muscle, ligaments, and all other tissues and intersegmental forces that caused the observed motions were calculated using a Newtonian inverse-dynamics approach.[59] The directions of all joint kinetic and kinematic data are expressed using the right-hand rule.

Kinetic and Kinematic Variables

Kinetic and kinematic data were filtered using a fourth-order zero-lag Butterworth low-pass filter at 40 and 20 Hz, respectively.[6,45] Kinematic data were linearly interpolated to align with kinetic data. The dependent measures were as follows:

- 3D trunk, hip, knee, and ankle angles at IC and at the peak over the stance phase
- Sagittal knee joint angular displacement over the stance phase (peak angle − IC angle)
- Peak knee extensor, adductor, and external rotator moments
- Peak hip extensor, abductor, and external rotator moments
- Peak ankle plantarflexion moment
- Peak vertical GRF over the stance phase
- Knee joint stiffness (peak knee extensor moment / knee joint angular displacement[48])
- Leg stiffness (peak vertical GRF / center of mass [COM] vertical displacement from the IC to its minimum)[32]

Joint moments are expressed as the internal moments. All kinetic data were normalized to body mass (in kilograms). All kinematic and kinetic variables of interest from the dominant leg data, which were identified by asking the participants which leg they used to kick a ball,[54] were extracted from the first landing of the standard and header DVJ tasks using custom MATLAB scripts (MathWorks). For each parameter, the average value over 3 trials was used for analysis.

Statistical Analysis

Data were analyzed using SPSS Statistics for Windows (Version 25.0; IBM Corp). We screened the data to ensure that assumptions were met for statistical analysis. The Shapiro-Wilk test was used to assess the normality of the data distribution. The paired-samples t test was used to compare data between DVJ conditions for each lower extremity biomechanical parameter. The effect size (Cohen d) was calculated using the following formula: $\eta^2 = t^2 / [t^2 + (N - 1)]$. Effect size values were interpreted as follows: 0.01 = small effect, 0.06 = moderate effect, and 0.14 = large effect.[8] The Wilcoxon signed-rank test was used when the assumption of normality in the data was violated. The effect size for this test was calculated by dividing the Z value by the square root of N, where N is the number of observations over the 2 time points.[42] The criteria for interpreting the effect sizes were as follows: 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect.[8]

Additionally, for each biomechanical variable, the correlation between the values in the 2 conditions was calculated by the Pearson correlation coefficient or the Spearman rank-order correlation (for nonparametric correlations). Significance was accepted at the 95% confidence level for all parameters ($P < .05$).

RESULTS

There were significant differences between the DVJ conditions regarding the following variables: peak knee flexion angle (P = .002; η^2 = 0.357), knee flexion displacement (P = .015; η^2 = 0.233), hip flexion angle at IC (P = .001; η^2 = 0.364), peak trunk flexion angle (P = .006; η^2 = 0.729), trunk frontal angle at IC (P < .0001; η^2 = 0.560), peak trunk frontal angle (P = .003; η^2 = 0.606), COM vertical displacement (P = .010; η^2 = 0.26), peak ATSF (P = .020; η^2 = 0.212), knee joint stiffness (P = .017; η^2 = 0.23), and leg stiffness (P = .046; η^2 = 0.16). Tables 1 to 4 report group means, standard deviations, and effect sizes for the header DVJ condition and correlation analysis results for knee joint, hip joint, trunk, ankle, peak vertical GRF, COM vertical displacement, and leg and knee joint stiffness variables.

The following variables were smaller in the header DVJ condition than in the standard DVJ condition: knee flexion angle at IC (which approached significance; P = .05), peak knee flexion angle, knee flexion displacement, hip flexion angle at IC, peak trunk flexion angle, and COM vertical displacement. However, the trunk lateral flexion angle at IC, peak trunk lateral flexion angle, peak ATSF, knee joint stiffness, and leg stiffness were larger in the header DVJ condition than in the standard DVJ condition. There was an almost perfect correlation (r = 0.632-0.908) between values in the 2 conditions for each aforementioned variable. There were no significant differences in ankle kinetics and kinematics, as well as peak vertical GRFs, between the conditions.

DISCUSSION

The present study examined the relationships and differences in kinetics and kinematics between standard and header DVJ conditions to clarify whether performing a secondary cognitive task (heading a soccer ball) could increase ACL injury risk during landing from a jump. The most

TABLE 1
Results of Group Comparisons and Correlational Tests for Biomechanical Parameters of the Knee Joint[a]

	Group Comparisons, Mean ± SD			Effect of Heading		Correlation		
Variable	DVJ	Header DVJ	P	Δ	d	r_P	r^2	P
Knee flexion angle, deg								
At IC	−27.28 ± 5.56	−25.83 ± 5.34	.050	1.45	0.157	0.800	0.640	<.001
Peak	−101.48 ± 11.39	−96.13 ± 9.55	.002[b]	5.35	0.357	0.768	0.590	<.001
Knee flexion displacement, deg	−74.19 ± 11.97	−70.30 ± 10.01	.015[c]	3.89	0.233	0.799	0.638	<.001
Knee angle at IC, deg								
Valgus	0.27 ± 4.02	−0.07 ± 4.42	.423	−0.34	0.028	0.886	0.785	<.001
Internal rotation	−1.89 ± 4.70	−2.20 ± 5.87	.703	−0.32	0.006	0.733	0.537	<.001
Peak knee angle, deg								
Valgus	−6.28 ± 6.79	−6.64 ± 7.49	.585	−0.36	0.013	0.905	0.819	<.001
Internal rotation	9.59 ± 6.99	9.14 ± 7.27	.335	−0.45	0.040	0.952	0.906	<.001
Peak ATSF, N/kg	−2.81 ± 1.00	−3.53 ± 1.81	.020[c]	−0.72	0.212	0.632	0.399	<.001
Peak knee moment, N·m/kg								
Extensor	2.47 ± 0.39	2.50 ± 0.42	.578	0.03	0.014	0.772	0.596	<.001
Adductor	0.71 ± 0.31	0.75 ± 0.37	.313	0.043	0.044	0.834	0.696	<.001
External rotator	−0.20 ± 0.07	−0.23 ± 0.089	.106	−0.026	0.110	0.625	0.391	.001

[a]Δ, DVJ with heading DVJ; ATSF, anterior tibial shear force; DVJ, drop vertical jump; IC, initial contact; r_P, Pearson correlation coefficient.
[b]Statistically significant difference ($P < .01$).
[c]Statistically significant difference ($P < .05$).

TABLE 2
Results of Group Comparisons and Correlational Tests for Biomechanical Parameters of the Hip Joint[a]

	Group Comparisons, Mean ± SD			Effect of Heading		Correlation		
Variable	DVJ	Header DVJ	P	Δ	d	r_P	r^2	P
Hip flexion angle, deg								
At IC	42.54 ± 8.91	39.70 ± 8.97	.001[b]	−2.84	0.364	0.908	0.824	<.001
Peak	19.94 ± 8.03	18.14 ± 9.46	.103	−1.81	0.111	0.835	0.697	<.001
Hip angle at IC, deg								
Adduction	−8.78 ± 4.59	−8.70 ± 4.89	.910	0.08	<0.001	0.737	0.543	<.001
Internal rotation	2.65 ± 4.84	2.24 ± 6.52	.712	−0.41	0.006	0.578	0.334	.003
Peak hip angle, deg								
Adduction	−0.64 ± 5.63	−0.48 ± 6.60	.793	0.16	0.003	0.890	0.792	<.001
Internal rotation	8.63 ± 5.32	7.10 ± 6.55	.121	−1.54	0.102	0.708	0.501	<.001
Peak hip moment, N·m/kg								
Extensor	−3.91 ± 1.31	−3.94 ± 1.26	.903	−0.03	<0.001	0.577	0.333	.003
Abductor	−1.87 ± 0.83	−1.89 ± 1.04	.878	−0.021	0.001	0.772	0.596	<.001
External rotator	−0.57 ± 0.24	−0.57 ± 0.29	.797	0.008	0.003	0.867	0.752	<.001

[a]Δ, DVJ with heading DVJ; DVJ, drop vertical jump; IC, initial contact; r_P, Pearson correlation coefficient.
[b]Statistically significant difference ($P < .01$).

important findings of the present study were the significant reductions in the peak and displacement knee flexion angles and hip flexion angle at IC during landing in the header DVJ condition as compared with the standard DVJ condition. Decreased peak trunk flexion angle and COM vertical displacement and increased peak ATSF, knee joint stiffness, leg stiffness, and trunk lateral flexion angle at IC and its peak were also observed during landing in the header DVJ condition versus the standard DVJ condition. Although the joint kinetic and kinematic values for individuals were correlated in the 2 conditions, these results generally support our hypothesis that heading a soccer ball during a DVJ increases risky lower extremity and trunk kinetic and kinematic characteristics during landing when compared with those during a DVJ without heading a ball.

High positive correlations ($r = 0.577\text{-}0.952$) between the DVJ conditions were observed for all variables. The significant differences in the aforementioned variables, with large effect sizes, indicate that the participants reliably performed the tasks in each condition and that the task condition significantly influenced the trunk and lower extremity biomechanics. Therefore, the present study yielded reliable and significant data elucidating the effects of heading a ball on landing kinetics and kinematics.

TABLE 3
Results of Group Comparisons and Correlational Tests for Biomechanical Parameters of the Trunk[a]

	Group Comparisons, Mean ± SD			Effect of Heading		Correlation	
Variable	DVJ	Header DVJ	*P*	Δ	*d*	r_s	*P*
Trunk flexion angle, deg							
At IC	−31.53 (25.96)	−29.83 (23.53)	.290	1.7	0.216	0.851	<.001
Peak	−46.91 (21.52)	−33.80 (22.81)	.006[b]	13.11	0.729	0.850	<.001
Trunk lateral flexion angle, deg							
At IC	6.44 (7.35)	7.99 (10.63)	<.001[b]	1.55	0.560	0.855	<.001
Peak	2.58 (5.28)	3.92 (9.44)	.003[b]	1.34	0.606	0.843	<.001

[a]Δ, DVJ with heading DVJ; DVJ, drop vertical jump; IC, initial contact; IQR, interquartile range; r_S, Spearman rank order correlation.
[b]Statistically significant difference ($P < .01$).

TABLE 4
Results of Group Comparisons and Correlational Tests for Biomechanical Parameters of the Ankle, Normalized Peak Vertical GRF, COM Vertical Displacement, and Leg and Knee Joint Stiffness[a]

	Group Comparisons, Mean ± SD			Effect of Heading		Correlation		
Variable	DVJ	Header DVJ	*P*	Δ	*d*	r_P	r^2	*P*
Ankle plantarflexion								
Angle at IC, deg	−41.52 ± 11.18	−43.02 ± 8.95	.393	−1.50	0.032	0.669	0.448	<.001
Peak moment, N·m/kg	−1.41 ± 0.25	−1.43 ± 0.22	.620	−0.019	0.011	0.698	0.487	<.001
Peak vertical GRF, N/kg	25.42 ± 4.14	25.62 ± 5.31	.791	0.19	0.003	0.744	0.554	<.001
COM vertical displacement, m	0.27 ± 0.057	0.25 ± 0.047	.010[b]	−0.02	0.26	0.745	0.555	<.001
Stiffness								
Knee joint, N·m/kg/deg	0.034 ± 0.008	0.037 ± 0.010	.017[b]	0.002	0.23	0.879	0.773	<.001
Leg, N/kg/m	97.62 ± 28.43	106.08 ± 33.47	.046[b]	8.46	0.16	0.811	0.658	<.001

[a]Δ, DVJ with heading DVJ; COM, center of mass; DVJ, drop vertical jump; GRF, ground-reaction force; IC, initial contact; r_P, Pearson correlation coefficient.
[b]Statistically significant difference ($P < .05$).

The present results indicate that participants landed with the trunk more upright and laterally tilted toward the dominant leg in the header DVJ condition than in the standard DVJ condition. The position and orientation of the trunk are thought to significantly influence the lower extremity kinetics and kinematics.[4,5,51,53] An association has also been shown between lateral trunk bending during landing and increased ACL injury rates[13,23] as well as increased ACL loading.[12,20,61] Upright and laterally tilted trunk positions are often observed during actual ACL injuries.[7,17,19,49] Thus, our finding that the trunk was more upright and tilted toward the dominant leg in the header DVJ condition than in the standard DVJ condition indicates that heading a ball may increase ACL injury risk in the dominant leg.

In the present study, the knee and hip flexion angles at IC, peak knee flexion, and knee flexion displacement were reduced in the header DVJ condition versus the standard DVJ condition. Additionally, we observed a significant reduction in the COM vertical displacement in the header DVJ condition as compared with the standard DVJ condition, which may be mainly attributed to the reductions in knee flexion displacement angles and peak trunk flexion angle. Reductions in knee and hip flexion angles during the impact phase of landing have been reported to increase the risk of ACL injury.[44,46,52] When knee flexion decreases, the angle between the patellar tendon and the tibial shaft increases, resulting in an increased amount of force directed anteriorly relative to the tibia.[37,38] Furthermore, when the knee flexion angle is shallow, the knee flexor musculature cannot provide a large amount of posterior force to the tibia, thus increasing the ATSF.[52] It was also reported that receiving a ground-reaction impact force with shallow knee flexion angles may increase the tibial axial force. In this situation, more tibial axial force may be translated to ATSF, especially when an individual has a larger posterior slope on the tibial plateau.[50] The ACL is the major restraint against anterior shear forces applied to the tibia relative to the femur, especially with the knee at near full extension; thus, the application of a knee loading at a shallow knee flexion angle produces greater ACL strain than that at deeper knee flexion angles.[46,52,60] The header DVJ condition also showed a significant increase in peak ATSF versus that in the standard DVJ condition. Taken together, the results indicate that a soccer player may have increased ACL injury risk during a dual task—landing while heading a ball—than during a controlled landing task.

In the present study, adding heading a ball as an external focus during DVJ did not affect the kinematics and kinetics of the ankle joint. It seems that significant changes in the ankle are not required to head a soccer ball during the DVJ task as compared with the standard DVJ task. Given the shock attenuation capability of the ankle joint, ankle plantarflexion angle during the landing phase has been associated with the GRF.[1,27] Therefore, the lack of a difference in peak vertical GRFs between the conditions can be attributed to the lack of a difference in any variable of interest at the ankle.

Participants exhibited higher leg and knee joint stiffness in the header DVJ condition than in the standard DVJ condition. Because the peak vertical GRFs and knee extensor moment did not significantly differ between conditions, the significant increases in knee joint and leg stiffness may be due to reduced knee joint flexion excursion angles and COM vertical displacement, respectively. Increased knee joint stiffness and leg stiffness have been suggested as ACL injury risk factors in previous biomechanical[32] and prospective[28,29] studies. For example, Leppänen et al[29] reported that an increased risk of ACL injury was associated with stiff landings. Collectively, these biomechanical changes in the header DVJ condition indicate that landing while heading a soccer ball is a riskier motion for the ACL than landing without performing any other task.

We compared the kinetic and kinematic variables between the header and standard DVJ conditions because when ACL injuries occur in real-world performances, athletes are usually under dual-task conditions.[25,39] As discussed earlier, the present study results demonstrated kinetic and kinematic characteristics that may be associated with increased ACL loading in the header DVJ condition versus the standard DVJ condition. These results are consistent with previous studies[2,10,15,34] that examined the effects of a dual task on landing mechanics associated with increased ACL loading. The inclusion of heading a soccer ball in a DVJ task influenced the attention of the participants; they were not solely focused on the DVJ task, creating a more cognitively demanding environment for the participants. Therefore, worse performance in the header DVJ task than in the standard DVJ task could be attributed to the capacity model of attention.[9,47,56] According to this model, which assumes that attention is a component of mental capacity, individuals have a limited capacity to perform mental work, and different activities impose different demands on this limited capacity.[22] When divided attention is required, the processing of sensory information is disrupted (eg, visual and auditory input), resulting in a reduced ability to accurately predict the motor plan and degrading the performance on landing in athletes.[21] To the best of our knowledge, this is the first study to better simulate actual tasks performed in soccer, such as landing in header situations. This design shifts the attentional focus away from the landing and reflects one of the most common playing situations associated with noncontact ACL injuries.[14,58] The present results showed that some ACL injuries related to sagittal- and frontal-plane biomechanics may be accentuated in the header DVJ condition. On the basis of these results, an examiner may be able to identify ACL injury risk–related movements more accurately using the header DVJ task, with improved sensitivity and specificity for ACL injury risk as compared with the standard DVJ. However, the header DVJ task is relatively complex and risky, as well as time-consuming in terms of the setup requirements for a large number of participants. Thus, applying the header DVJ task as a screening task for ACL injury risk should be applied with caution.

Limitations

There are some limitations to this study. First, the participants were collegiate soccer athletes. Thus, these results may not be applicable to other age groups. In future studies, researchers should aim to examine whether these findings can be generalized to other populations. Second, this study did not assess whether participants with risky landing characteristics in the header DVJ condition actually showed increased ACL injury risk. Our conclusion is based on theoretical models of ACL injury, strain mechanisms, and risk factors. Further prospective studies are needed to examine this relationship. Third, it is unclear whether these results hold true for other landing styles. Thus, our findings may be limited to similar tasks, and future studies should examine the validity of these findings on other tasks, such as cutting or single-leg landings. Fourth, our results were based on analyzing mixed samples of male and female athletes. Given the sex differences in ACL injury risk, future studies should examine sex differences in biomechanical responses to landing under dual-task conditions.

CONCLUSION

The present study results suggest that the inclusion of heading a ball as an external focus in the DVJ task alters frontal- and sagittal-plane trunk kinematics and sagittal-plane lower extremity biomechanics, possibly increasing the risk of ACL injury. These results indicate that acquiring the ability to safely perform jump-landing skills under a secondary cognitive task, such as heading a ball, may be beneficial for prevention of ACL injury or reinjury. Thus, header DVJs may be incorporated into an ACL injury prevention or rehabilitation program.

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