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Original Article

Effects of a soccer-specific vertical jump on lower extremity landing kinematics

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ABSTRACT

Anterior cruciate ligament (ACL) injury frequently occurs in female soccer athletes during deceleration movements such as landings. In soccer, landings mostly occur following jumping headers. Little research has been done to determine the mechanics that follow and how they compare to standard drop vertical jumps (DVJ). The purpose of this study was to analyze differences in kinematics between the DVJ and the soccer-specific vertical jump (SSVJ) in female soccer athletes to better assess the sport-specific risk for ACL injury. A secondary aim was to compare second landings (L2) to first landings (L1). Eight female recreational soccer athletes performed DVJs and SSVJs initiated from a 31 cm height. Motion capture was performed during landings and data were analyzed using repeated-measures ANOVA. SSVJs produced less peak hip flexion ($p = 0.03$) and less peak knee flexion ($p = 0.002$) than DVJs. SSVJs also demonstrated increased ankle plantarflexion at initial contact (IC) than DVJs ($p = 0.005$). L2s produced less peak hip ($p = 0.007$) and knee flexion ($p = 0.002$) than L1s. SSVJs and L2s displayed a more erect landing posture than the DVJs and L1s at the hip and knee, a known ACL risk factor. The significant results between jump styles show that the SSVJ displays mechanics that are different from the DVJ. The SSVJ may be a better sport-specific screening tool for ACL injury mechanisms than the DVJ in soccer athletes as it has a more direct translation to the sport.

Introduction

In recent years, the popularity of women's soccer has drastically increased in the United States. With the surge in popularity, there has also been an increase in injuries, notably to the anterior cruciate ligament (ACL).[1] ACL injury typically requires surgery accompanied by a lengthy recovery. Following an ACL injury, the likelihood of re-injury and development of osteoarthritis is much higher.[2,3] Soccer is a dynamic sport in which several movements that put the ACL at risk are regularly performed. Additionally, females appear to be at a higher risk than males due to extrinsic and sex-specific intrinsic factors. There appears to be a need to study the female soccer athlete's risk of ACL injury in sport-specific movements.

ACL tears most often occur as non-contact injuries,[4–7] which occur frequently in soccer due to improper mechanics during jump landings as deceleration takes place.[8,9] Extensive research has been done to better understand landing mechanics and the risks involved.[10–17] Kinematic and kinetic mechanisms have been linked to ACL injury risk including deficiencies in hip and knee flexion,[18–20] increased valgus angles and moments at the knee,[21–24] high vertical ground reaction forces (GRF),[22,25] and high anterior tibial shear forces.[7,26] Additionally, muscle activation patterns before, during, and immediately following initial contact (IC) have been recognized as potential factors.[27] The most notable risk factor associated with activation patterns is poor quadriceps-hamstrings co-contraction.[27]

In soccer, the primary motivation for field players to jump is to head the ball. Proper heading form requires the player to rotate and flex the trunk to meet the ball, then reposition to a more erect posture before landing.[28] Studies have shown that landing from a jump with the trunk in a more upright position may lead to increased tibiofemoral joint loading.[29,30] This suggests that landing mechanics following heading may be attributable to factors influencing ACL injury risk.

Studies have used the drop vertical jump (DVJ) task to analyze joint kinematics and their relationships with ACL injury mechanisms.[19,31,32] Recently, researchers have begun to investigate not only the first landing of the DVJ, but the second landing as well.[33,34] It has been concluded that the second landing of a DVJ displays characteristics of a more rigorous

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Abbreviations

DVJ	drop vertical jump
SSVJ	soccer-specific vertical jump
ACL	anterior cruciate ligament
GRF	ground reaction forces
ROM	range of motion
L1	first landing
L2	second landing
IC	initial contact
SD	standard deviation

task than the first.[34] It has also been suggested that the second landing should be compared to the first to discover differences in how forces are mechanically absorbed.[33] DVJs have been adapted to analyze landing from rebounds in basketball, however no current research has adapted this jump to the soccer header. One study has analyzed kinematics during landing from a header in conjunction with a stop jump.[35] While these findings suggested increased stiffness occurs during landings following headers, research remains limited on the ACL risk factors that emerge from a soccer-specific jump landing.[35] Risk factors identified in the DVJ serve as a good baseline, but the incidence of ACL injury especially in female soccer players remains high. This suggests that additional measures need to be taken to better understand sport-specific movement.

The purpose of this study was to analyze the differences between landings in 3-D lower extremity kinematics in female soccer athletes to better assess the risk for ACL injury in header landings. It was hypothesized that more biomechanical tendencies associated with ACL risk factors would emerge from the header landings. Furthermore, it was expected that decreased knee and hip flexion, increased knee valgus, and an overall more erect posture would be observed in soccer-specific vertical jump (SSVJ) landings when compared to normal DVJ landings.

Materials & methods

Experimental procedures

Eight healthy female soccer athletes participated in this study (20.88 ± 1.17 years; 1.68 ± 0.06 m; 58.77 ± 7.65 kg). All participants had at least five years of experience playing soccer, no lower extremity injuries in the last six months, no previous knee surgery requiring reconstruction, no neurological condition impairing their ability to jump or head a soccer ball, and were not currently taking anti-vertigo medications. Participants were recreationally active for at least 30 min on three days of the week at a moderate intensity. All participants read and signed a university-approved informed consent form detailing the study. The study was approved by the Ball State University institutional review board (IRB #1672880-2).

Upon arrival, all participants changed into lab-provided standardized cross-trainer shoes (Nike WMNS T-Lite VII Leather, Beaverton, OR, USA) and their own compression clothing. A cycle ergometer (Monark 818 Ergomedic, Vansbro, Sweden) was used to provide a 3-min minimal lower-body warm-up before testing jump height. A vertec jump system (Sports Imports, Columbus, OH, USA) was used to measure three maximum effort countermovement jumps to determine the height of the soccer ball. A hanging soccer ball was suspended from a metal rod and set so that the ball hung at 50% of maximum countermovement jump height, directly above the landing platforms.[35] This height was selected because it was expected to elicit near maximal effort during the jumping header task,[35] but was also consistently achievable for all participants.

Anthropometric measures were taken, and 43 retro-reflective markers (14-mm width) were attached to the skin using a modified Plug-in Gait Model (Vicon Motion System Ltd., Oxford, UK). Following preparation, static and movement calibration trials were collected. Participants then completed a modified standard dynamic warm-up (4.5 min, 9 stretches for 30 s each) across a 10 m performance floor.[36] Once completed, two jump tasks were explained. Kinematic data were collected for all jumping trials using 8 Vicon Vantage and Vero Motion Capture cameras, and Vicon Nexus software (v2.11.0, Vicon Motion System Ltd., Oxford, UK).

The DVJ task began with participants standing on top of a 31 cm box aligned so participants could step off and land with one foot on each of two AMTI OR6-7 force platforms embedded side by side into the floor (Advanced Mechanical Technologies Inc., Watertown, MA, USA). Force platforms were used to identify initial contact for kinematic measures. Upon landing, participants performed a maximum vertical jump with 100% effort, then landed again with one foot on each force platform. SSVJ was completed in the same manner, however upon landing from the box, participants jumped and headed the soccer ball affixed in the air before landing again on the force platforms. For both jump types, the landing following the initial drop-off of the box was identified as landing one (L1), while the landing following the jump task was identified as landing two (L2). Participants were given three to five practice repetitions of each jump type for familiarization before beginning collection trials. Jump trials were completed for both tasks until three to four successful trials of each were collected. Participants were given 30 s rest between trials and 60 s rest between conditions to avoid fatigue. Successful trials required the participant to step off, not jump, from the box and to land with each foot entirely on separate force platforms in both landings.

Data processing

Vicon Nexus software (v2.11.0) was used for the initial processing of motion capture data. Further processing was conducted in Visual 3D 2020 × 64 (C-Motion, Germantown, MD, USA). Whole-body kinematics were collected and processed. Kinematic data were low pass filtered using a dual-pass Butterworth filter with cutoff frequencies of 8 Hz. Initial contact and take-off events were established when vertical force crossed a 20 N threshold. Angles at IC, peak angles, and range of motion (ROM) were recorded in the sagittal and frontal planes for the hip, knee, and ankle. Joint ROM was calculated as the difference between maximum and minimum angles during the landing phase for each jump, which was defined as initial contact until peak knee flexion. Peak vertical GRF was normalized by dividing by the body mass of each participant.

Statistical analysis

Statistical analyses of the variables of interest were performed with SPSS software (Version 26.0, IBM, Inc., Armonk, NY, USA). Repeated measures ANOVAs were performed on all kinematic variables to analyze the main effects of jump (DVJ vs. SSVJ) and landing (L1 vs. L2). When a significant jump*landing interaction was observed ($p < 0.05$), post-hoc simple effect pairwise comparisons were considered between SSVJ-L1 and -L2, and between DVJ-L2 and SSVJ-L2. Greenhouse-Geisser corrections were used when the assumption of sphericity was violated. Cohen's d (d) effect size was reported for all variables. A Bonferroni confidence interval adjustment and an alpha level of 0.05 were used for all tests.

Results

Participants completed all landing trials and all aspects of the study without difficulty. Before comparing the results from the two jump styles and landings, a dependent t-test was performed on the center of mass displacement during the jumps. The mean jump height of the DVJ was 2.5 ± 1.8 cm higher than the mean of the SSVJ ($p = 0.008$). There was no significant difference in peak vertical GRF based on jump type (DVJ: 18.65 ± 4.36 N/kg; SSVJ: 19.62 ± 4.43 N/kg; $p = 0.273$) or landing (L1: 18.81 ± 4.52 N/kg; L2: 19.46 ± 4.29 N/kg; $p = 0.319$).

Results from repeated measures ANOVAs revealed a significant main effect for jump type in variables in the trunk, hip, knee, and ankle (Tables 1 and 2). In the sagittal plane, SSVJ produced less ROM in the trunk ($F[1,7] = 14.87$; $p = 0.006$), hip ($F[1,7] = 13.99$; $p = 0.007$), and knee ($F[1,7] = 7.829$; $p = 0.027$) compared to DVJ. SSVJ also demonstrated less peak hip flexion ($F[1,7] = 7.377$; $p = 0.03$) and less peak knee flexion ($F[1,7] = 22.633$; $p = 0.002$) angles during landing than DVJ. At IC, SSVJ landings had less knee flexion ($F[1,7] = 8.723$; $p = 0.021$) and more plantarflexion ($F[1,7] = 16.838$; $p = 0.005$) than DVJ landings. Higher peak knee adduction angles ($F[1,7] = 6.211$; $p = 0.04$) were observed in DVJ landings, while increased knee abduction angles at maximum knee flexion ($F[1,7] = 9.943$; $p = 0.016$) were observed in SSVJ landings.

When comparing across landings, significant differences were also observed at the trunk, hip, knee, and ankle (Tables 1 and 2). L2 had significantly less knee sagittal plane ROM ($F[1,7] = 5.729$; $p = 0.048$) and less hip frontal plane ROM ($F[1,7] = 9.727$; $p = 0.017$) compared to L1. However, a significant interaction of jump*landing ($p = 0.043$) was also present for hip frontal ROM. Results from post-hoc simple effect pairwise comparisons indicated significant differences between SSVJ-L1 and SSVJ-L2 ($p = 0.003$). While a significantly lower ROM was observed during SSVJ compared to DVJ across both landings, the ROM in SSVJ-L2 was also significantly lower compared to SSVJ-L1.

L2 produced significantly less peak hip flexion ($F[1,7] = 14.253$; $p = 0.007$), less peak knee flexion ($F[1,7] = 24.728$; $p = 0.002$), less peak dorsiflexion ($F[1,7] = 11.099$; $p = 0.013$), and more plantarflexion at IC ($F[1,7] = 9.828$; $p = 0.016$) compared to L1. Within the frontal plane, L1 produced higher peak hip abduction ($F[1,7] = 9.672$; $p = 0.017$), higher hip abduction at IC ($F[1,7] = 7.169$; $p = 0.032$), and higher peak knee adduction ($F[1,7] = 7.041$; $p = 0.033$) than L2.

Furthermore, trunk flexion at IC was significantly less in L2 ($F[1,7] = 10.11$; $p = 0.015$) compared to L1. However, a significant interaction of jump*landing was also present in trunk flexion at IC ($p = 0.034$). Post-hoc simple effect pairwise comparisons revealed that trunk flexion only decreased significantly from DVJ-L1 to DVJ-L2 ($t[7] = 4.57$; $p = 0.003$). Although a slight decrease occurred from SSVJ-L1 (16.5°) to SSVJ-L2 (13.66°), the difference was not significant ($t[7] = 0.689$; $p = 0.513$). Therefore, the effect of trunk flexion on landing was dependent on whether the subject was completing a DVJ or SSVJ.

Discussion

This study explored differences in landing mechanics between a jumping header in soccer and a standard drop vertical jump (DVJ). The purpose was to determine if the soccer-specific vertical jump presents ACL injury risk factors in female soccer athletes. Previous research has investigated landings from a soccer header after a stop jump, but has only discussed sagittal plane kinematics between sexes.[35] No known study has assessed how landing mechanics from an SSVJ compare to a DVJ, which has been identified as a screening tool for ACL injury mechanisms.[37,38] Similar research incorporating sport-specific jumps within DVJs has been conducted on female basketball players.[33,34] The current study was the first to assess DVJs alongside soccer-specific jumps. This approach allowed the DVJs to serve as a baseline when comparing SSVJs. Although the difference in jump height between DVJ and SSVJ was significant, it was relatively small at 2.5 ± 1.8 cm ($p = 0.008$). This indicates that the effect of jump type on height was minimal, and demonstrates the strength of design for the SSVJ that it was approaching the maximal effort jump height in the DVJ. Furthermore, there was no significant difference between peak vertical GRF based on jump type or landing ($p > 0.05$). This indicates that the SSVJ also elicited close to maximal effort. As hypothesized, primary findings supported that SSVJs present more kinematic risk factors than DVJs, and that L2s present more risk factors than L1s.

Results from the current study showed greater knee extension during landing in the SSVJ compared to the DVJ, and in L2 compared to L1 (Table 1). Decreased knee flexion during landing has been associated with increased ACL loading in recreational males and females performing DVJs.[39] Additionally, landing with less knee flexion has been associated with increased ACL injury risk in female basketball and floorball players.[37] Model-simulation of a similar task found ACL strain peaked at low knee flexion angles during IC.[16] It appears that altering the DVJ to include the heading task can further limit knee flexion during the landing phase.

Greater ROM observed in the knee during L1 compared to L2 may be related to the need to generate impulse for a maximal effort jump. Future studies should investigate the relationship between subsequent jumps on previous landing movement patterns to draw a substantive conclusion. Nonetheless, the resultant knee joint positioning during L2 can be tied to higher risk of injury. Peak vertical GRF was not significantly different between L1 and L2. In L2, these forces are absorbed throughout a limited range of motion, which may place greater stress on the joint. This indicates that the preparation for the jump in L1 also serves to lessen the burden on the knee joint. The results of the current study support the findings of previous research comparing first and second landings in the DVJ.

Peak hip flexion during landing was also reduced in SSVJs and L2s (Table 1). Limited hip flexion in single-leg landings has been shown to

Table 1
Kinematic variables for the trunk, hip, knee, and ankle in the sagittal plane. Values expressed as mean (*SD*).

	Variable	DVJ		SSVJ		Effect Size (*d*)	
		Land 1	Land 2	Land 1	Land 2	Jump	Landing
TRUNK	Trunk ROM (°)	21.87 (9.5)	19.15 (10.05)	16.22 (10.72)	12.36 (8.2)	**0.647~**	0.342ˆ
	Trunk flexion angle @ IC (°)	21.53 (4.72)	5.9 (9.3)	16.5 (5.85)	13.66 (7.9)	0.196	**1.295***
HIP	Hip ROM (°)	48.28 (11.13)	41.32 (16.07)	41.83 (12.80)	27.62 (12.94)	**0.761~**	0.796~
	Hip peak flexion angle (°)	89.69 (8.20)	67.57 (16.79)	78.69 (10.59)	56.31 (18.74)	**0.817***	**1.566***
	Hip flexion angle @ IC (°)	52.29 (33.43)	26.24 (5.5)	46.87 (31.29)	28.78 (9.67)	0.072	0.939*
KNEE	Knee ROM (°)	68.25 (10.78)	58.31 (12.39)	65.68 (9.24)	49.23 (14.15)	**0.500~**	**1.123***
	Knee peak flexion angle (°)	96.06 (10.05)	80.30 (14.76)	89.62 (11.41)	68.68 (13.10)	**0.732~**	**1.476***
	Knee flexion angle @ IC (°)	27.81 (10.43)	21.99 (8.16)	23.94 (7.94)	19.45 (7.40)	**0.376ˆ**	0.606~
ANKLE	Ankle ROM (°)	51.43 (19.66)	53.98 (17.59)	53.78 (17.48)	54.38 (16.48)	0.077	0.089
	Ankle peak dorsiflexion angle (°)	37.06 (3.92)	36.56 (5.23)	37.62 (3.92)	32.45 (4.61)	0.381ˆ	**0.608~**
	Ankle plantarflexion angle @ IC (°)	15.64 (17.59)	18.58 (17.89)	17.94 (17.15)	22.06 (14.89)	**0.184**	**0.265ˆ**

Trunk: Positive value represents flexion; negative value represents extension.
Abbreviations.
SD: standard deviation; DVJ: drop vertical jump; SSVJ: soccer-specific vertical jump; ROM: range of motion; IC: initial contact.
Bold indicates significant difference ($p < 0.05$).
Effect size calculated as Cohen's *d*.
*Large effect size (≥ 0.8).
~Medium effect size (0.5–0.8).
ˆSmall effect size (0.2–0.5).

Table 2
Kinematic variables for the hip and knee in the frontal plane. Values expressed as mean (*SD*).

	Variable	DVJ		SSVJ		Effect Size (*d*)	
		Land 1	Land 2	Land 1	Land 2	Jump	Landing
HIP	Hip ROM (°)	7.31 (4.27)	4.41 (1.46)	9.06 (4.30)	3.33 (2.76)	0.105	**1.278***
	Hip peak abduction angle (°)	−10.75 (5.20)	−8.53 (4.73)	−11.30 (3.97)	−7.73 (4.06)	0.027	**0.645**∼
	Hip abduction angle @ IC (°)	−11.98 (7.62)	−7.26 (3.86)	−12.35 (6.10)	−7.00 (4.65)	0.009	**0.881***
KNEE	Knee ROM (°)	10.76 (6.58)	9.78 (6.29)	11.45 (6.37)	8.98 (5.40)	0.008	0.280ˆ
	Knee peak adduction angle (°)	7.13 (7.15)	5.58 (6.11)	6.47 (6.35)	4.29 (5.53)	**0.154**	**0.296**ˆ
	Knee peak abduction angle (°)	−3.62 (10.15)	−4.20 (9.78)	−4.98 (9.93)	−4.69 (8.30)	0.096	0.015
	Knee abduction angle @ peak knee flexion (°)	0.10 (11.36)	−0.18 (10.33)	−2.30 (11.38)	−1.91 (9.58)	**0.194**	0.006

Abbreviations.
SD: standard deviation; DVJ: drop vertical jump; SSVJ: soccer-specific vertical jump; ROM: range of motion; IC: initial contact.
Bold indicates significance ($p < 0.05$).
Effect size calculated as Cohen's *d*.
*Large effect size (≥ 0.8).
∼Medium effect size (0.5–0.8).
ˆSmall effect size (0.2–0.5).

contribute to ACL strain.[10] These results were consistent with previous research on female basketball players comparing first and second landings in DVJs.[34] The significant differences in peak sagittal plane motion at the hip and knee between both jump type and landing suggest that the SSVJ-L2 may exacerbate known ACL risk factors of hip and knee extension during landing.

Differences in lower extremity joint flexion between SSVJ-L1 and L2 were consistent with results from literature examining landing from headers following stop jumps in female soccer players.[35] Butler et al. observed greater peak angles in the first landing for ankle dorsiflexion, knee flexion, and hip flexion angles of 1°, 18°, and 14° respectively.[35] Similarly, the current study observed greater peak angles in SSVJ-L1 for ankle dorsiflexion, knee flexion, and hip flexion angles of 5°, 21°, and 22° respectively. These results suggest that increased stiffness during landing is present following headers.[35] A review of current literature identified stiff landings as a trend that may increase the risk for ACL injury.[40]

Previous analysis of a mathematical model suggested that landing following a jump header could put players in a more upright posture due to trunk repositioning following head impact with the ball.[28] This landing position has been shown to increase tibiofemoral joint loading.[29,30] While the current study did not incorporate a moving ball, which was integral to previous model-based analyses, it provides insight into landing posture following ball impact. The current study had a significant interaction of jump*landing for trunk flexion at IC. However, SSVJ-L2 did not exhibit more trunk extension at IC as was hypothesized. Instead, the trunk remained flexed during both SSVJ landings. This may be explained by the nature of the two jumps. In DVJs, participants jumped straight up before landing, compared to the SSVJ where participants had to flex the trunk to meet the ball, and thus landed with more trunk flexion. Increased trunk flexion throughout the landing phase of drop jumps has been associated with increased hip and knee flexion in healthy men and women.[41,42] In the current study however, increased trunk flexion at IC did not translate into increased hip and knee flexion. This suggests the importance of implementing sport-specific assessments in a clinical setting and adjusting training strategies to mimic the sport more closely.

Knee abduction angles have been reported as a predictor of ACL injury.[22,32] Results of the current study showed no significant findings for frontal plane ROM or peak knee abduction. However, there was a significant main effect for jump type on knee abduction angle at peak knee flexion. The SSVJ showed a more valgus alignment during landing than the DVJ ($p = 0.016$; $ES = 0.194$). ACL strain and anterior shear forces at the tibia are higher when the knee is in a valgus position.[10,25,43,44] The combination of increased knee abduction angle and reduced peak flexion angle in the knee during SSVJs displays multiplanar risk factors, which have been suggested to be more likely to cause injuries than single-planar mechanisms.[45]

Hip abduction at IC was significantly less in L2 compared to L1. This finding does not support the hypothesis. Hip abduction angles greater than 20° at IC have been previously observed in video analysis of ACL injuries in female handball and basketball players,[46] and in male professional soccer players.[47] Values from the current study did not approach 20°. Therefore, it is suggested that the significantly higher hip abduction values in L1s may not be associated with increased injury risk.

Findings from the current study have a strong clinical significance for the female soccer population. The significant results between jump styles indicate that the SSVJ displays mechanics that are different from the standard DVJ. Although the DVJ is often used as a screening tool,[37,38] the SSVJ may be more appropriate as it has a direct translation to the sport. Athletic trainers and sports medicine professionals should consider implementing a more header-like jump to identify players with limited lower extremity flexion that occurs following headers.

The extension that occurred at the hip and knee in SSVJ-L2s may be linked with higher ankle plantarflexion at IC. This suggests that the ankle may take on some of the forces that would normally dissipate at the knee. This strategy does not seem to be an efficient countermeasure to lessen landing impact at the knee and hip. On the contrary, the landing position seen in SSVJ-L2s may also indicate increased injury risk to the ankle joint as it is in a less stable position. Practitioners may need to consider the dual risk seen in this landing mechanism when developing intervention programs by encouraging landing in a flexed knee position. This could potentially reduce the risk of injury at both the knee and ankle.

Certain limitations of a laboratory setting were present during the study and may have affected the results. In a real-life scenario, a soccer player would be wearing cleats and landing on grass or turf rather than wearing cross-trainers while landing on a performance floor. Restricting participants to land squarely on the force plates may have altered their natural landing tendencies. In a real match situation, the soccer ball would also be coming towards the player with a velocity rather than being still at the time of contact. Additionally, researchers encountered difficulties in participant recruitment, leading to an acceptable but less-than-ideal sample size. To help address this, Cohen's *d* effect sizes were calculated for all values to indicate the strength of statistical relationships. Medium to large effect sizes were seen for multiple significant variables, indicating the trend would likely continue with larger sample sizes.

Conclusion

The current study analyzed kinematic variables during DVJs and SSVJs in female soccer athletes to determine the influence of jumping headers on landing mechanics. The main findings demonstrated that SSVJs and L2s were performed with greater hip and knee extension during landing. These results were consistent with the hypothesis that landings following headers would display more risk for ACL injuries. Trunk flexion at IC did not support the hypothesis that greater extension would be observed in SSVJs or L2s. However, this result has clinical significance supporting the SSVJ as a more accurate screening and training method than the DVJ for soccer athletes.

It is evident that SSVJs cause a more extended lower extremity upon landing than DVJs. The SSVJ may be a good tool for screening or performance enhancement in female soccer players, potentially providing a more sport-specific prediction of injury. Further research should be conducted to further validate the application of the soccer-specific vertical jump in a clinical setting. Future studies should also continue to break down the movement by examining the influence of subsequent jumps on the previous movement pattern to further validate the effects of the soccer-specific vertical jump on landing mechanics.

Conflict of interest

The authors declare that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements). or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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Ethical approval statement

The study was approved by the Ball State University institutional review board (IRB #1672880-2). All participants read and signed a university-approved informed consent form detailing the study.

Authors’ contribution

Conceived and designed the analysis: Mancini, Dickin, Hankemeier, and Wang.

Collected the data: Mancini, Welch, and Wang Contributed data or analysis tools: Mancini and Wang Performed the analysis: Mancini, Dickin, and Wang Wrote the paper: Mancini, Ashton, and Wang

Other contributions: Dickin and Hankemeier provided guidance during study design, interpretation and write-up. Ashton edited paper. Welch contributed to research process

Submission statement

The authors confirm that this work has not been previously published, nor is it currently under consideration for publication elsewhere. All of the authors approve this work for publication and if accepted, it will not be published elsewhere without written consent of the copyright-holder.

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