

# Peak Lower Extremity Landing Kinematics in Dancers and Nondancers

Bethany L. Hansberger, DAT\*; Shellie Acocello, PhD, ATC†; Lindsay V. Slater, PhD‡; Joseph M. Hart, PhD, ATC, FNATA, FACSM‡; Jatin P. Ambegaonkar, PhD, ATC, OT, CSCS§

\*Towson University, MD; †University of Tennessee, Chattanooga; ‡University of Virginia, Charlottesville; §George Mason University, Manassas, VA

**Context:** Anterior cruciate ligament (ACL) injuries often occur during jump landings and can have detrimental short-term and long-term functional effects on quality of life. Despite frequently performing jump landings, dancers have lower incidence rates of ACL injury than other jump-landing athletes. Planned versus unplanned activities and footwear may explain differing ACL-injury rates among dancers and nondancers. Still, few researchers have compared landing biomechanics between dancers and nondancers.

**Objective:** To compare the landing biomechanics of dancers and nondancers during single-legged (SL) drop-vertical jumps.

**Design:** Cross-sectional study.

**Setting:** Laboratory.

**Patients or Other Participants:** A total of 39 healthy participants, 12 female dancers (age = 20.9 ± 1.8 years, height = 166.4 ± 6.7 cm, mass = 63.2 ± 16.4 kg), 14 female nondancers (age = 20.2 ± 0.9 years, height = 168.9 ± 5.0 cm, mass = 61.6 ± 7.7 kg), and 13 male nondancers (age = 22.2 ± 2.7 years, height = 180.6 ± 9.7 cm, mass = 80.8 ± 13.2 kg).

**Intervention(s):** Participants performed SL-drop-vertical jumps from a 30-cm-high box in a randomized order in 2 activity (planned, unplanned) and 2 footwear (shod, barefoot) conditions while a 3-dimensional system recorded landing biomechanics.

**Main Outcome Measure(s):** Overall peak sagittal-plane and frontal-plane ankle-, knee-, and hip-joint kinematics (joint angles) were compared across groups using separate multivariate analyses of variance followed by main-effects testing and pairwise-adjusted Bonferroni comparisons as appropriate ( $P < .05$ ).

**Results:** No 3-way interactions existed for sagittal-plane or frontal-plane ankle (Wilks  $\lambda = 0.85$ ,  $P = .11$  and Wilks  $\lambda = 0.96$ ,  $P = .55$ , respectively), knee (Wilks  $\lambda = 1.00$ ,  $P = .93$  and Wilks  $\lambda = 0.94$ ,  $P = .36$ , respectively), or hip (Wilks  $\lambda = 0.99$ ,  $P = .88$  and Wilks  $\lambda = 0.97$ ,  $P = .62$ , respectively) kinematics. We observed no group × footwear interactions for sagittal-plane or frontal-plane ankle (Wilks  $\lambda = 0.94$ ,  $P = .43$  and Wilks  $\lambda = 0.96$ ,  $P = .55$ , respectively), knee (Wilks  $\lambda = 0.97$ ,  $P = .60$  and Wilks  $\lambda = 0.97$ ,  $P = .66$ , respectively), or hip (Wilks  $\lambda = 0.99$ ,  $P = .91$  and Wilks  $\lambda = 1.00$ ,  $P = .93$ , respectively) kinematics, and no group × activity interactions were noted for ankle frontal-plane (Wilks  $\lambda = 0.92$ ,  $P = .29$ ) and sagittal- and frontal-plane knee (Wilks  $\lambda = 0.99$ ,  $P = .81$  and Wilks  $\lambda = 0.98$ ,  $P = .77$ , respectively) and hip (Wilks  $\lambda = 0.88$ ,  $P = .13$  and Wilks  $\lambda = 0.85$ ,  $P = .08$ , respectively) kinematics. A group × activity interaction (Wilks  $\lambda = 0.76$ ,  $P = .02$ ) was present for ankle sagittal-plane kinematics. Main-effects testing revealed different ankle frontal-plane angles across groups ( $F_{2,28} = 3.78$ ,  $P = .04$ ), with male nondancers having greater ankle inversion than female nondancers ( $P = .05$ ).

**Conclusions:** Irrespective of activity type or footwear, female nondancers landed with similar hip and knee kinematics but greater peak ankle eversion and less peak ankle dorsiflexion (ie, positions associated with greater ACL injury risk). Ankle kinematics may differ between groups due to different landing strategies and training used by dancers. Dancers' training should be examined to determine if it results in a reduced occurrence of biomechanics related to ACL injury during SL landing.

**Key Words:** drop-vertical jump, barefoot condition, shod condition, unplanned perturbation

## Key Points

- Overall, female dancers and female and male nondancers landed with similar hip and knee kinematics.
- Female nondancers landed from a single-legged drop-vertical jump with greater peak ankle eversion and less ankle dorsiflexion than female dancers and male nondancers.
- Dance training should be evaluated to determine if it results in positions that place individuals at reduced risk for anterior cruciate ligament injury during single-legged drop-vertical jump landings.

Patients with approximately 130 000 anterior cruciate ligament (ACL) injuries are treated surgically each year in the United States, resulting in a \$1.4 billion direct financial burden.<sup>1</sup> Furthermore, indirect financial costs and reduced quality of life<sup>2</sup> are often associated comorbidities. Researchers<sup>2,3</sup> have shown that patients with

ACL injuries often develop osteoarthritis even after reconstruction, further reducing knee function and overall activity levels.

Incidence rates of ACL injury vary depending on risk factors, such as sex,<sup>4-6</sup> knee anatomy and structure,<sup>7-9</sup> fatigue,<sup>10-15</sup> footwear and shoe-surface interface,<sup>16,17</sup> and

lower extremity biomechanics.<sup>5,6,18–23</sup> By sport, women's gymnastics has the highest incidence rate (0.33 per 1000 athlete-exposures [AEs]), followed closely by women's soccer (0.28 per 1000 AEs) and women's basketball (0.23 per 1000 AEs).<sup>24</sup> Approximately 40% to 92% of ACL injuries are due to noncontact mechanisms,<sup>25–27</sup> frequently occurring while landing from a jump.<sup>25,28</sup> Inappropriate lower extremity alignment and neuromuscular control during maneuvers that involve rapid deceleration or quick changes in direction are commonly experienced in sports such as basketball, gymnastics, and soccer. These movements place athletes in positions that increase the risk for ACL injury, including greater knee valgus during landing<sup>6,18,23</sup> and reduced maximal knee-flexion angle.<sup>23</sup>

Conversely, female modern and ballet dancers have a much lower rate of ACL injury (0.015 and 0.005 per 1000 AEs, respectively).<sup>25</sup> Dancers perform jumps that involve landing from midair rotation, an intricate combination of characteristics that athletes in other jump-landing sports do not necessarily practice repeatedly. The repeated practice potentially results in a muscle-memory pattern<sup>29,30</sup> that becomes familiar to the dancer as he or she anticipates the next jump in a series or the next turn in the routine. Movement anticipation may result in changes that allow an individual to maintain posture and balance in preparation for perturbation.<sup>31,32</sup>

Regardless of sex, dancers have similar ACL injury rates<sup>25</sup> and use landing patterns similar to those of male athletes (eg, less knee valgus).<sup>33–35</sup> These observations could suggest that the landing strategies dancers use may be associated with less biomechanical injury risk than for female athletes participating in sports with high ACL injury risks.<sup>5,6</sup> Still, few researchers have examined whether dancers use specific protective biomechanical strategies during activities with high-risk motions. Therefore, the purpose of our study was to determine if the landing biomechanics of female dancers differed from those of nondancing male and female athletes during single-legged drop-vertical jumps (SL-DVJs).

## METHODS

We conducted a cross-sectional, repeated-measures descriptive laboratory study to compare the landing biomechanics of female dancers with those of female and male nondancers during an SL-DVJ task. Dependent variables were peak sagittal- and frontal-plane ankle, knee, and hip kinematics and kinetics during the landing phase. Independent variables were footwear (barefoot, shod) and activity condition (planned, unplanned).

### Participants

A total of 39 healthy individuals participated in this study: 12 female dancers (age = 20.9 ± 1.8 years, height = 166.4 ± 6.7 cm, mass = 63.2 ± 16.4 kg), 14 female nondancers (age = 20.2 ± 0.9 years, height = 168.9 ± 5.0 cm, mass = 61.6 ± 7.7 kg), and 13 male nondancers (age = 22.2 ± 2.7 years, height = 180.6 ± 9.7 cm, mass = 80.8 ± 13.2 kg). Participants were recruited from a National Collegiate Athletic Association Division I university's student body and the surrounding area. To be included, dancers needed a minimum of 5 years' experience in dance, whereas nondancers needed a minimum of 5 years'

experience in soccer or basketball; at the time of the study, all participants had to be recreationally active for an average of 30 minutes at least 3 days per week. Volunteers were excluded if they were actively and simultaneously participating in multiple club-level sports of interest (eg, soccer and dance); had a history of lower extremity injury in the 6 months before the study; or had any history of major knee injury, such as ligament damage. All participants provided written informed consent, and the Institutional Review Board for Health Sciences Research of the University of Virginia approved this study.

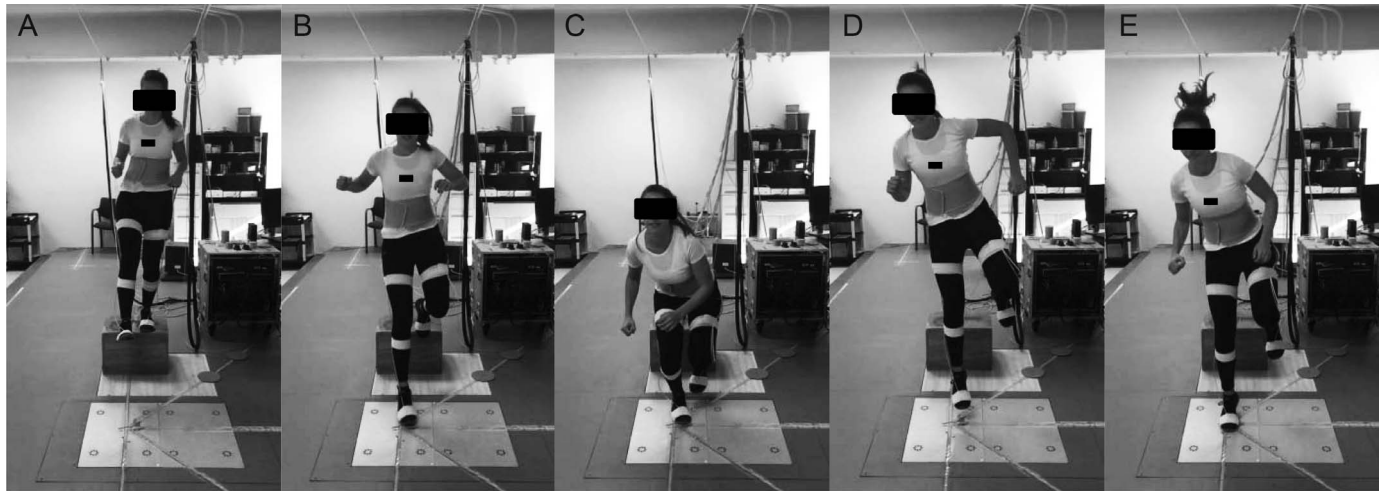
### Instruments

Three-dimensional joint kinematics of the ankle, knee, and hip were measured using the Flock of Birds (Ascension Technologies Inc, Burlington, VT) electromagnetic motion-analysis system controlled by The MotionMonitor software (Innovative Sports Training Inc, Chicago, IL). A nonconductive force plate (Bertec Corp, Columbus, OH) was used to collect ground reaction forces for determining initial ground contact and peak ground reaction force. We simultaneously collected motion-analysis data at a sampling rate of 144 Hz and force-plate data at a sampling rate of 1000 Hz. A global reference system was defined using the right-hand rule so that all movements in the anterior, left, and superior directions were positive. Lower extremity joint rotations were determined using the Euler rotation method in the *y*, *x*, *z* order: the *y*-axis corresponded to the flexion-extension axis, the *x*-axis corresponded to the abduction-adduction axis, and the *z*-axis corresponded to the internal-external-rotation axis.

### Testing Procedures

Participants reported to the laboratory for a single testing session. Tracking sensors were placed bilaterally on the lateral thigh, lateral shank, and dorsum of the foot and on the superior sacrum and midthorax. Each sensor was secured using double-sided tape, prewrap, and athletic tape. To digitize each joint and identify joint centers, we identified 16 landmarks on the lower trunk and each lower extremity: the top of the head; the spinous processes of the C7, T12, and L5 vertebrae; bilateral anterior-superior iliac spines of the pelvis; the medial and lateral joint lines of each knee; the medial and lateral malleoli of each ankle; and the second distal phalanx of each foot. The hip-joint center was identified using the Bell et al<sup>36</sup> method. After all sensors were placed, the sensor cords were bundled together and secured to the participant using an elastic strap. Each joint was digitized during initial intake at each session, and the randomized SL-DVJs occurred after participant setup.

We demonstrated the SL-DVJ to the participants and allowed them to practice until comfortable with the tasks in both the barefoot and shod conditions. After a study investigator (B.L.H.) deemed each participant competent to perform the task, he or she performed a series of 6 SL-DVJs as described in previous studies,<sup>5,23,37</sup> with a modification of a planned (3 SL-DVJs) or unplanned (3 SL-DVJs) ball toss (Figures 1 and 2). The 6 trials were conducted in a random order determined using the Latin square method. Participants rested for 1 minute between trials to prevent fatigue effects. For the SL-DVJ, they stood in double-limb



**Figure 1.** Phases of the planned single-legged drop-vertical jump. A, Beginning of the jump. B, Initial contact. C, Maximal knee flexion during the loading phase. D, Maximal vertical jump. E, Landing from the jump.

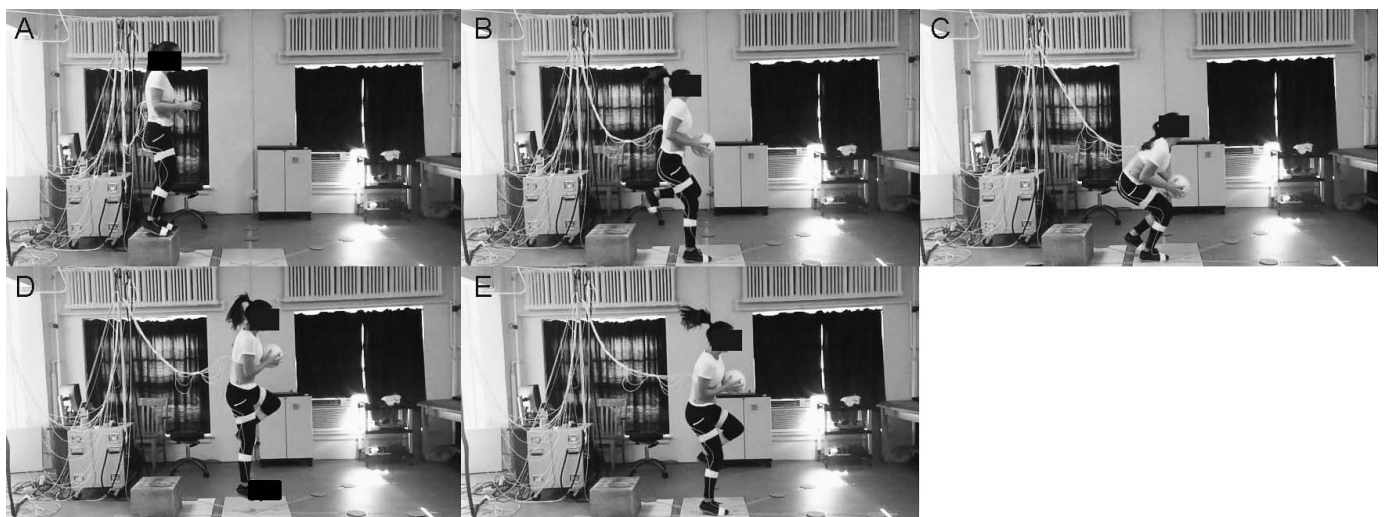
stance on a 30-cm box placed at a standardized distance (one-third of their height) from the force plate. We instructed them to drop off the box onto the force plate, perform a single-legged landing on their dominant leg, and immediately perform a maximal-effort vertical jump, landing a second time on the single leg. We defined the *dominant leg* as the preferred landing limb. In the unplanned condition, participants performed the same activity while simultaneously catching a ball during the drop portion of the test. The ball was thrown directly toward each participant by the same clinician (B.L.H.) standing at the same spot, which was marked by tape on the floor, for each trial. A trial was considered *successful* only if data collection was not faulty, sensor placement was accurate throughout the entire trial, and the participant did not fall during the trial. If a trial was unsuccessful, the participant repeated it until 3 successful trials were obtained for each condition. The series of 6 randomized SL-DVJs was performed in both the shod and barefoot conditions for a total of 12 jumps.

### Data Processing

Kinematic data were low-pass filtered at 14.5 Hz with a zero-lag, fourth-order Butterworth filter.<sup>38</sup> The kinematic variables were reduced using custom user-defined equations in The MotionMonitor software by identifying initial contact (IC) after the drop from the box and takeoff for the vertical jump using vertical ground reaction force. The instant at which vertical ground reaction force exceeded 20 N was identified as IC. Three trials during each condition were normalized to 101 frames, and the average of the 3 trials was used to calculate the kinematic variables. The landing phase of each SL-DVJ included all values obtained between IC and achievement of peak knee flexion; however, we examined only the overall peak of the kinematic values achieved between these time points.

### Statistical Analysis

Overall sagittal- and frontal-plane ankle-, knee-, and hip-joint angle peaks during landing were compared using 3 (group)  $\times$  2 (activity)  $\times$  2 (footwear) multivariate analyses



**Figure 2.** Phases of the unplanned single-legged drop-vertical jump. A, Beginning of the jump. B, Initial contact. C, Maximal knee flexion during the loading phase. D, Maximal vertical jump. E, Landing from the jump.

**Table 1. Overall Peak Sagittal-Plane Angles Among Female Dancers, Female Nondancers, and Male Nondancers During Single-Legged Drop-Vertical Jump From 30 cm<sup>a</sup>**

Sagittal-Plane Angle	Group Main Effect		Group × Activity Interaction			Group × Footwear Interaction			Group × Activity × Footwear Interaction		
	Mean ± SE, °	F Value	Planned	Unplanned	Wilks λ	P Value	Shod	Barefoot	Wilks λ	P Value	
			Mean ± SE, °				Mean ± SE, °				
Ankle		0.77			0.76	.02 <sup>b</sup>			0.94	.43	.11
Female dancers	4.1 ± 2.5		5.0 ± 2.5 <sup>c</sup>	3.3 ± 2.6 <sup>c</sup>			1.4 ± 2.4	6.8 ± 3.0			
Female nondancers	-0.2 ± 2.4		-0.1 ± 2.4	-0.3 ± 2.5			-2.9 ± 2.3	2.6 ± 2.9			
Male nondancers	2.5 ± 3.0		2.3 ± 2.9 <sup>c</sup>	2.7 ± 3.0 <sup>c</sup>			-2.1 ± 2.8	7.1 ± 3.6			
Knee		0.83			0.99	.81			0.97	.60	.93
Female dancers	58.0 ± 2.7		57.3 ± 2.8	58.8 ± 2.7			58.2 ± 2.8	57.8 ± 2.6			
Female nondancers	55.0 ± 2.4		54.3 ± 2.4	55.7 ± 2.3			54.9 ± 2.5	55.1 ± 2.3			
Male nondancers	59.5 ± 2.8		58.5 ± 2.9	60.6 ± 2.8			59.1 ± 2.9	59.9 ± 2.7			
Hip		0.78			0.88	.13			0.99	.91	.88
Female dancers	42.4 ± 4.1		40.7 ± 4.1	44.1 ± 4.3			42.4 ± 4.2	42.4 ± 4.1			
Female nondancers	37.3 ± 3.7		36.3 ± 3.6	38.3 ± 3.8			37.2 ± 3.7	37.5 ± 3.7			
Male nondancers	43.9 ± 4.3		44.2 ± 4.3	43.7 ± 4.5			44.0 ± 4.4	43.8 ± 4.3			

Abbreviation: SE, standard error.

<sup>a</sup> Positive values indicate ankle dorsiflexion, knee flexion, and hip flexion.

<sup>b</sup> Indicates difference ( $P < .05$ ).

<sup>c</sup> Indicates greater dorsiflexion than in female nondancers.

of variance followed by simple main-effects testing and pairwise-adjusted Bonferroni comparisons as appropriate. We set the  $\alpha$  level a priori at equal to or less than .05. All statistical analyses were performed using SPSS (version 20.0; IBM Corp, Armonk, NY).

## RESULTS

### Ankle Kinematics

No 3-way interactions or group × footwear differences were found for sagittal-plane or frontal-plane ankle kinematics. We observed group × activity interactions for sagittal-plane ankle kinematics (Wilks  $\lambda = 0.76$ ,  $F_{2,28} = 4.4$ ,  $P = .02$ , partial  $\eta^2 = 0.24$ , power = 0.71; Table 1). Dancers and male nondancers demonstrated greater ankle dorsiflexion during both activity conditions than the neutral position maintained by female nondancers.

The multivariate analyses of variance revealed a group main effect for ankle frontal-plane angles ( $F_{2,28} = 3.78$ ,  $P = .04$ , partial  $\eta^2 = 0.21$ , power = 0.64; Table 2). Post hoc testing showed a trend toward greater peak ankle inversion in male nondancers than in female nondancers (mean difference =  $10.7^\circ \pm 1.6^\circ$ ,  $P = .052$ ).

### Knee Kinematics

We did not observe 3-way interactions or group × activity or group × footwear differences in sagittal-plane or frontal-plane knee kinematics. No group main effects for peak knee kinematics were found (Tables 1 and 2).

### Hip Kinematics

No 3-way interactions or group × activity or group × footwear differences in sagittal-plane or frontal-plane hip kinematics were present. We did not demonstrate group main effects for hip kinematics (Tables 1 and 2).

## DISCUSSION

The purpose of our study was to examine differences in peak landing kinematics between female dancers and male and female nondancers during an SL-DVJ activity. Our primary findings were that, irrespective of activity type or footwear, female nondancers had similar peak knee and hip kinematics during landing, greater peak ankle eversion, and less peak ankle dorsiflexion (ie, positions associated with greater ACL injury risk) compared with female dancers and male nondancers. Neither footwear nor activity type affected ankle frontal-plane or sagittal-plane kinematics across groups.

### Ankle Kinematics

During the SL-DVJ, female nondancers displayed more ankle eversion than male nondancers, with a trend toward more eversion than dancers. This observation is in agreement with previous studies in which researchers reported that females landed in more eversion than males during drop landing<sup>27</sup> and side-stepping or cutting tasks<sup>39,40</sup> and with greater peak pronation during drop landings.<sup>41</sup> Furthermore, authors<sup>42</sup> examining dancers' biomechanics noted that dancers with ankle injuries landed in more eversion than uninjured dancers. Individuals who sustained

**Table 2. Overall Peak Frontal-Plane Angles Among Female Dancers, Female Nondancers, and Male Nondancers During Single-Legged Drop-Vertical Jump From 30 cm<sup>a</sup>**

Frontal-Plane Angle	Group Main Effect			Group × Activity Interaction			Group × Footwear Interaction			Group × Activity × Footwear Interaction			
	Mean ± SE, °	F Value	P Value	Planned	Unplanned	Wilks λ	P Value	Shod	Barefoot	Wilks λ	P Value	Wilks λ	P Value
Ankle		3.78	.04 <sup>b</sup>	Mean ± SE, °			.29	Mean ± SE, °			0.96	.55	.55
Female dancers	9.0 ± 2.8			8.8 ± 2.8	9.2 ± 2.8	0.92		3.3 ± 3.5	14.6 ± 2.9			0.96	
Female nondancers	0.9 ± 2.7			1.0 ± 2.6	0.9 ± 2.7			-3.3 ± 3.3	5.1 ± 2.8				
Male nondancers	11.6 ± 3.3			11.8 ± 3.2	11.4 ± 3.3			4.9 ± 4.1	18.4 ± 3.4				
Knee		2.28	.12	Mean ± SE, °			.77	Mean ± SE, °			0.97	.66	.36
Female dancers	6.1 ± 1.7			6.1 ± 1.7	6.1 ± 1.8	0.98		6.3 ± 1.7	5.9 ± 1.8			0.94	
Female nondancers	5.0 ± 1.5			4.9 ± 1.5	5.1 ± 1.6			5.1 ± 1.5	4.9 ± 1.6				
Male nondancers	10.0 ± 1.8			9.8 ± 1.8	10.2 ± 1.9			10.0 ± 1.8	9.9 ± 1.9			1.00	.93
Hip		2.66	.09	Mean ± SE, °			.08	Mean ± SE, °			0.97	.62	.62
Female dancers	6.8 ± 2.2			7.5 ± 2.2	6.0 ± 2.2	0.85		6.3 ± 2.2	7.2 ± 2.3			0.97	
Female nondancers	9.0 ± 1.9			9.0 ± 1.9	9.0 ± 2.0			8.4 ± 1.9	9.6 ± 2.0				
Male nondancers	2.1 ± 2.3			3.1 ± 2.3	1.1 ± 2.3			1.6 ± 2.3	2.6 ± 2.4				

Abbreviation: SE, standard error.

<sup>a</sup> Positive values indicate ankle inversion, knee varus, and hip adduction.

<sup>b</sup> Indicates difference ( $P < .05$ ).

ACL injuries had greater pronation than uninjured individuals.<sup>43</sup> Excessive ankle eversion, a component of pronation, has been suggested to create a valgus force at the knee, resulting in greater stress on the ACL.<sup>44</sup>

Performing the SL-DVJ during the planned or unplanned activity did not change ankle sagittal-plane or frontal-plane kinematics between groups. Dancers and male nondancers consistently had higher peak ankle dorsiflexion and inversion, whereas female nondancers maintained a more neutral position with ankle eversion. Even with the introduction of a distraction, the dancers had greater peak ankle dorsiflexion in both planned and unplanned conditions than the male and female nondancers (Table 1). Greater ankle dorsiflexion is associated with greater force attenuation during landing, as reductions in ankle dorsiflexion are correlated with greater knee-valgus<sup>45</sup> and knee-flexion<sup>46</sup> displacement. Although landing technique at the ankle did not worsen for any group while distracted, the dancers' specific landing technique or training may translate into sport activities in which unanticipated movements are common.

### Knee Kinematics

Landing from an SL-DVJ<sup>41</sup> or running<sup>47</sup> in ankle pronation is often accompanied by knee valgus, a position known to increase ACL injury risk.<sup>6,18,23</sup> In a prospective study of biomechanical injury risk, Hewett et al<sup>23</sup> reported that athletes who sustained an ACL injury landed in positions of knee abduction that were 7.6° to 8.4° greater than in athletes who did not sustain an ACL injury during an SL-DVJ. In our study, we did not observe differences in peak knee valgus among groups. Whereas we did not find differences in peak frontal-plane knee-valgus angle between dancers and female nondancers, the 1.1° difference in our study is outside the 2.5° to 4.4° difference range between female athletes and female dancers in the literature.<sup>35,48</sup> A possible explanation for the different findings may be that our dancers were not professional dancers; they were recreational dancers who had at least 5 years of experience but had not attained an elite or semiprofessional level. In addition, the female dancers studied by Orishimo et al<sup>35</sup> and Liederbach et al<sup>48</sup> had an average age of 25 years, whereas our dancers had an average age of 20 years; dancers who began training at younger ages displayed advantageous changes in landing biomechanics.<sup>34</sup> The differences in findings may also be attributable to other compensatory patterns, such as trunk anterior flexion or lateral flexion, which we did not examine.

### Hip Kinematics

Researchers<sup>19</sup> who analyzed video of ACL injuries reported that, at the point of (or just before) an ACL injury, the hip joint is in a position of adduction and internal rotation. The lack of group differences for hip kinematics in our study contrasts with the findings of investigators who identified that males landed with less hip flexion<sup>19</sup> and greater hip abduction<sup>21</sup> than females but agrees with those of authors<sup>49</sup> who demonstrated no sex differences in peak hip sagittal-plane or frontal-plane kinematics during landing. Although the literature on sex differences for hip kinematics is conflicting, the evidence is limited for

comparisons across different sport types; in our study, the landing strategies at the hip were similar across sports and both sexes.

### Dance Technique and Training

The differences seen at the ankle but not at the knee or hip among the groups may be attributed to the dancers' training and background. Dancers perform their choreographed set of movements repeatedly during their daily training. Over the course of training, dancers may adapt their landing strategy in a way that differs from that of nondancing female athletes. In addition, dance training emphasizes "lightness" (landing softly), which should be demonstrated while descending from a jump. Ballet dance techniques, such as the *sissonne fermée*, involve taking off from and landing in a position of ankle plantar flexion and knee extension, allowing dancers to maintain the aesthetic look of their sport while attenuating landing forces.<sup>42</sup> This initial ankle plantar flexion and knee extension is further attenuated as the dancer dorsiflexes the ankle on landing in a *plié* or *demi-plié* position. Furthermore, dancers are used to pointing their toes, which places the ankle in a plantar-flexed position and creates a habit of landing in a toe-to-heel pattern. Forefoot-first landings result in fewer ground reaction forces than do heel-to-toe landings.<sup>50</sup> These reduced ground reaction forces can attenuate the risk for ACL injury by reducing the load on the ACL. Specific types of dance training should be examined and compared to determine if they reduce the occurrence of biomechanics related to ACL injury during single-legged landing.

### LIMITATIONS

We acknowledge several study limitations. The dance participants had various dance-genre backgrounds and were not restricted to modern or ballet dancers. Thus, from our findings, we cannot discern which genre of training produced possible ACL-protective landing biomechanics. Researchers should examine landing biomechanics and ACL injury incidences across different dance genres. Still, across the multiple dance genres, our dance participants had multiple years of training. Given our cross-sectional study design, we also cannot state that dance training resulted in adaptations to landing biomechanics that reduced the risk of ACL injury. Additional research is also necessary to determine the most effective type (eg, ballet, modern), as well as the appropriate amount (frequency, time), of training to improve landing biomechanics.

To our knowledge, we are among the first to examine single-legged landing biomechanics at both single joints and multiple joints among dancers and nondancers. The dancers in our study had an average of 10 years of recreational experience in a variety of dance backgrounds; however, the experience levels of our dancers may not have been equivalent to those of the professional dancers studied by other investigators. Combining the previous examinations with our findings indicates the need to further assess not only the level but also the type of training to most effectively improve biomechanics and reduce the risk of ACL injury.

### CONCLUSIONS

Overall, all groups landed with similar knee and hip kinematics. However, female nondancers landed with greater peak ankle eversion and less peak ankle dorsiflexion (ie, positions associated with a greater risk of ACL injury). Specific styles of dance training should be evaluated to determine if they reduce the occurrence of biomechanics related to ACL injury during SL-DVJ landings.

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Address correspondence to Bethany L. Hansberger, DAT, Towson University, 8000 York Road, Towson, MD 21252. Address e-mail to [b\\_hansberger@yahoo.com](mailto:b_hansberger@yahoo.com).