Comparison of Landing Biomechanics Between Male and Female Professional Dancers

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Background: The incidence of anterior cruciate ligament injuries among dancers is much lower than that among team sport athletes and no clear gender disparity has been reported in the dance population. Although numerous studies have observed differences in lower extremity landing biomechanics between male and female athletes, there is currently little research examining the landing biomechanics of male and female dancers. Comparing landing biomechanics within this population may help explain the lower overall anterior cruciate ligament injury rates and the lack of gender disparity.

Hypothesis: Due to the fact that dancers receive jump-specific and balance-specific training from a very young age, we hypothesized that there would be no gender differences in drop-landing biomechanics in professional dancers.

Study Design: Controlled laboratory study.

Methods: Kinematics and ground-reaction forces were recorded as 33 professional modern and ballet dancers (12 men and 21 women) performed single-legged drop landings from a 30-cm platform. Joint kinematics and kinetics were compared between genders.

Results: No gender differences in joint kinematics or kinetics were found during landings (multivariate analysis of variance: $P = .490$ and $P = .175$, respectively). A significant relationship was found between the age at which the dancers began training and the peak hip adduction angle during landing ($r = .358$, $P = .041$).

Conclusion: In executing a 30-cm drop landing, male and female dancers exhibited similar landing strategies and avoided landing patterns previously associated with increased injury rates.

Clinical Relevance: Commonly reported biomechanical differences between men and women, as well as the gender disparity among athletes in the incidence of ACL injuries, may be the result of inadequate experience in proper balance and landing technique rather than intrinsic gender factors. Beginning jump-specific and balance-specific training at an early age may counteract the potentially harmful adaptations in landing biomechanics observed in female athletes after maturity.

Keywords: gender; anterior cruciate ligament (ACL); training; experience

The gender disparity in the incidence of noncontact anterior cruciate ligament (ACL) injuries among team sport athletes has been well documented.[10] Numerous studies have observed differences in lower extremity biomechanics between male and female athletes during landing and cutting activities.[3,4,6,12,13,21,23] On the basis of these biomechanical differences, factors placing female athletes at increased risk for ACL injury have been identified[9] and injury prevention programs focusing on proper landing technique and lower extremity alignment have been implemented to reduce these risk factors.[1,7,17,18,24]

Classical ballet and modern dance have been shown to be as physically demanding as many team sports (basketball, soccer, football, and volleyball) and very jump-intensive.[19] Throughout the course of their daily training and practice, dancers perform more than 200 jumping and landing activities.[15] Because of the aesthetic requirements of the performance, most of these landings are performed

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on a single outstretched leg, resulting in large forces being transmitted through the knee.[15,25,26] Combining these movement patterns with the high forces generated during landing and the number of repetitions performed, it seems that this population would be at high risk for ACL injury.

Despite these factors, dance has been shown to have a much lower incidence of ACL injuries (0.009 ACL injuries per 1000 exposures) compared with team sports (0.07 to 0.31 ACL injuries per 1000 exposures).[14] Additionally, no clear gender difference in the incidence of ACL injuries has been documented.[14] Although other factors unique to dance may be partially responsible for the low ACL injury rates in this population (ie, rehearsed choreography, shoe-surface interaction, etc), dancers must still execute numerous landing maneuvers with proper biomechanics to avoid injuries. Although previous research has demonstrated a link between gender differences in landing biomechanics and the gender disparity in ACL injury rates in equivalently trained team sport athletes, we are currently unaware of any research examining the landing biomechanics of male and female dancers. Characterizing and comparing landing biomechanics within this population may help explain the lower overall ACL injury rates and the lack of gender disparity. This may also give further insight into other factors contributing to the gender differences found in other athletic populations.

In addition to choreographed movements, 2 factors that may also protect dancers from ACL injuries are training and experience. Unlike basketball, soccer, and volleyball players who do not routinely receive training on landing technique, dancers are taught at an early age in highly specific jumping/landing techniques focused on the achievement of a particular aesthetic appearance.[14] Girls tend to start dance training at about 6 to 8 years of age, while boys begin at about 10 to 12 years. Perhaps the most unique aspect of dance training for jumping is the assumption of a fully extended lower extremity (knee and hip extension), including maximal plantar flexion in midair and the appearance of a smooth and effortless landing. Biomechanically, these 2 goals may be related in that dancers are trained to land with the lower extremities near full extension, with a vertical spine and with maximum use of plantar flexion at initial contact. Dancers land on the plantar surface of their phalanges and metatarsal heads and immediately "roll through their feet" with eccentric control to achieve a quiet heel touchdown. It is presumed that the extension of the lower extremity at initial contact provides increased use of the full range of lower extremity flexion to dissipate landing forces and to achieve the desired aesthetics of a smooth landing. There is also specific emphasis on controlling the alignment of their lower extremities during landing such that the center of the patella remains directly over the second ray of the foot. Advancement to the professional level is predicated on complete mastery of jumping and balance technique.[14]

The long-term effects of this training from a young age may act to protect dancers from noncontact ACL injury. The low incidence of ACL injuries in dancers of both sexes coupled with the fact that they receive intensive training in jumping and landing from a young age seems to suggest that technique and training may play a more prominent role in the commonly reported disparity in ACL injuries than gender-specific neuromuscular, anatomic, or hormonal factors. The purpose of this study was to compare lower extremity kinematics and kinetics during single-legged drop landings between male and female professional dancers. Given the experience level and elite professional status of our participants, we hypothesized that no difference in lower extremity biomechanics would exist between male and female dancers.

TABLE 1
Descriptive Data for Male and Female Participants[a]

	n	Height (cm)	Weight (kg)	Age (y)	Age at Start of Training (y)
Males	12	177.3 (5.8)[b]	71.3 (5.5)[b]	25 (4)	16 (2)[b]
Females	21	167.5 (4.9)	57.9 (6.3)	27 (5)	11 (4)

[a]Data shown as means, with standard deviation in parentheses.
[b]Significant difference between genders ($P < .005$).

MATERIALS AND METHODS

Participants

Thirty-three modern and ballet dancers (12 men and 21 women) were recruited from professional dance companies in the New York City area. All participants completed a medical history questionnaire and signed an informed consent form approved by the Institutional Review Board. Demographic information including height, weight, current age, and age at the start of systematic dance training are displayed in Table 1. To be included in this study, participants had to be currently active in a professional ballet or modern dance company, with no history of surgery to the lower extremities and no lower extremity injuries within the past year.

Drop Landings

Participants performed 3 single-legged drop landings from a 30-cm platform onto a force plate. They wore their own personal athletic shoes for the testing and all landings were performed on the dominant leg, which was defined as the leg that would be used to kick a ball for maximal distance. As illustrated in Figure 1, participants were required to cross their arms over their chest and begin each trial in single-limb stance on the dominant leg. They then dropped off the platform and landed on the force plate using the same leg.

3-Dimensional Motion Analysis

Twenty reflective markers were placed bilaterally over the calcaneus, second metatarsal, lateral malleolus, lateral femoral condyle, midshank, midthigh, anterior superior

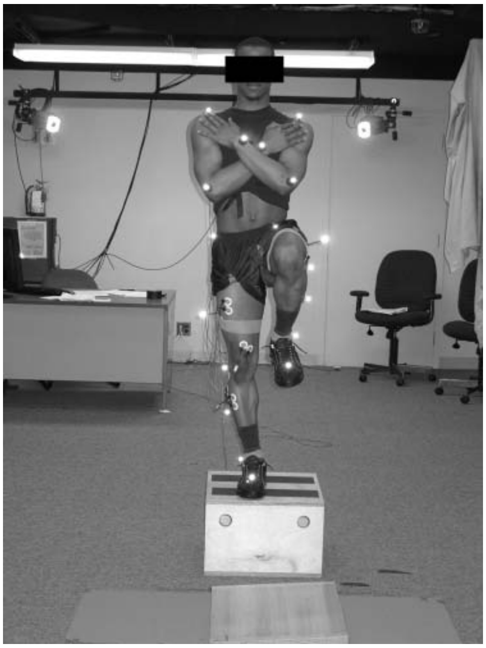

Figure 1. Laboratory set-up for 30-cm drop landings. Participants crossed their arms over their chest and started each trial in single-limb stance on the dominant leg. They then dropped off the platform and landed on the force plate using the dominant leg.

iliac spine, acromion, lateral humeral epicondyle, and distal radius. Two additional markers were placed on the sacrum and the left posterior superior iliac spine as per the Helen Hayes system. Marker positions were collected at 250 Hz using 8 Eagle cameras (Motion Analysis Corp, Santa Rosa, California). The motion data were then filtered with a fourth-order Butterworth low-pass filter with a cutoff frequency of 10 Hz to eliminate any high frequency noise. Ground-reaction forces were recorded at 2500 Hz with a multicomponent force plate (AMTI, Watertown, Massachusetts).

Data Analysis

Landings were defined from initial contact with the force plate to the maximum amount of knee flexion achieved during each trial. Sagittal and frontal plane joint angles were calculated for the ankle, knee, and hip using the motion capture data. Net joint moments were calculated for each joint by standard inverse dynamic techniques using specialized computer software (Visual 3D, C-Motion Inc, Rockville, Maryland). Joint angles and moments were assessed at the time of initial contact with the force plate and at the time of maximum knee flexion in both the sagittal and frontal planes. Peak joint moments and peak joint angles were also determined for each landing trial. All joint moments were normalized to body mass. Peak vertical ground-reaction force and loading rate were also determined.

According to Winter,[27,28] total support moment is a parameter that represents the total action of the whole leg to support the body and prevent it from collapsing when the leg is loaded during a movement task. The total support moment for each landing was calculated by adding the sagittal plane moments at the ankle, knee, and hip throughout the length of each trial.[27,28] The maximum value of the total support moment was then determined and the contribution of each joint to that maximum value was calculated. Mean values of the 3 trials were then calculated for each measurement within each participant.

Statistics

Two separate multivariate analyses of variance (kinematics and kinetics) were used to compare joint kinematics and kinetics between male and female dancers, followed by a t test when statistical significance was reached. Peak ground-reaction force and loading rate were compared using Student t tests to determine whether the overall demand of the landing task was different between genders. Student t tests were also used to compare landing phase duration, peak total support moment, and experience data between genders. Because dancers begin jumping and landing training at an early age and continually practice these techniques throughout their careers, Pearson correlation tests were performed to determine if a significant relationship exists between the age at which the dancers began training and variables previously described as being key determinants of ACL injury status (peak knee abduction angle, peak knee abduction moment, peak hip adduction angle, and peak hip adduction moment).[2,4,9] For all statistical analyses, $P < .05$ was considered significant.

RESULTS

Landing phase duration (from initial contact to maximum knee flexion) was similar for both male and female dancers (0.257 [0.075] seconds for men, 0.261 [0.059] seconds for women; $P = .327$).

Joint Kinematics

The multivariate analysis of variance revealed no significant gender difference in joint kinematics ($P = .490$) (Table 2). Both male and female dancers exhibited similar amounts of ankle, knee, and hip motion throughout the landings in both the frontal and sagittal planes.

Peak Vertical Ground-Reaction Force

Peak vertical ground-reaction force (normalized to body weight [BW]) was not found to be significantly different between male and female dancers (4.2 [0.7] BW for men, 3.9 [0.5] BW for women; $P = .209$). Group means for the vertical ground-reaction force from initial contact to maximum knee flexion are graphically represented in Figure 2. Additionally, the loading rate from initial contact to the peak vertical ground-reaction force was not different between genders (81.2 [22.1] BW/s for men, 79.0 [28.5] BW/s for women; $P = .810$).

TABLE 2
Sagittal and Frontal Plane Kinematic Data During 30-cm Drop Landing[a]

	Sagittal Plane			Frontal Plane		
Joint Angle (deg)	Ankle Dorsiflexion (+)	Knee Flexion (+)	Hip Flexion (+)	Ankle Eversion (+)	Knee Abduction (+)	Hip Adduction (+)
Initial contact						
Males	–33.2 (5.0)	1.0 (7.0)	–2.6 (10.7)	–12.9 (10.0)	–0.03 (2.5)	–10.3 (5.1)
Females	–34.2 (4.6)	3.5 (4.4)	5.9 (8.5)	–6.9 (7.5)	–1.3 (3.7)	–12.5 (5.0)
Max knee flexion						
Males	18.5 (4.0)	59.2 (12.5)	20.0 (16.6)	–0.7 (8.9)	–3.2 (4.3)	4.8 (5.3)
Females	17.0 (4.2)	58.7 (5.5)	28.7 (10.2)	1.2 (7.2)	–1.7 (11.1)	0.9 (5.4)
Range of motion						
Males	52.2 (5.8)	58.2 (8.7)	23.2 (6.7)	15.3 (7.9)	8.4 (4.8)	15.3 (5.1)
Females	51.5 (4.8)	55.1 (5.6)	23.3 (9.0)	12.7 (5.5)	11.5 (5.4)	15.4 (5.3)

[a]Data shown as means, with standard deviation in parentheses. Multivariate analysis of variance revealed no significant difference between genders (*P* = .490).

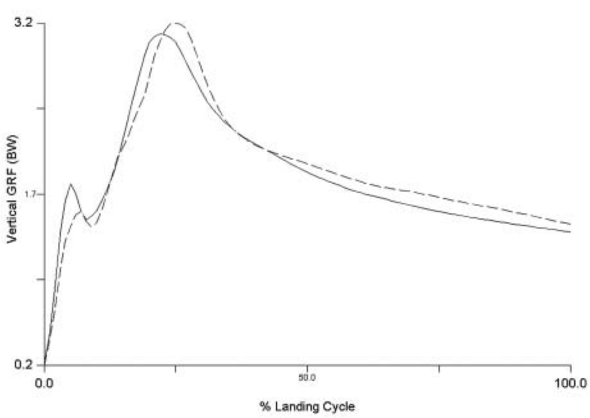

Figure 2. Group mean vertical ground-reaction forces from initial contact to maximum knee flexion. Mean vertical ground-reaction force (males, dashed line; females, solid line) normalized to percent of the landing cycle.

Joint Kinetics

No differences in sagittal and frontal plane joint moments were observed between male and female dancers (P = .175) (Table 3). Both groups exhibited minimal internal knee adduction moments throughout landing and generated large peak extension and abduction moments at the hip.

Peak Total Support Moment

No difference in peak total support moment was found between male and female dancers (*P* = .505) (Figure 3). The multivariate analysis of variance also revealed that individual contributions of the ankle, knee, and hip to the peak total support moment were not different between genders (*P* = .175). In both the male and female groups, the hip accounted for about 50% of the peak total support moment, while the knee and ankle contributed approximately 20% and 30%, respectively.

Experience and ACL Injury Indicators

Pearson correlation revealed a significant relationship between peak hip adduction angle during landing and the age at which the dancers began systematic training (*r* = .358, *P* = .041) (Figure 4), while peak knee abduction angle (*P* = .340), peak knee abduction moment (*P* = .301), and peak hip adduction moment (*P* = .522) were not significant.

DISCUSSION

In contrast to previous research comparing landing biomechanics between male and female athletes,[3,4,6,12,13,21,23] our study found no difference in lower extremity kinetics and kinematics between male and female professional dancers. Both genders maintained neutral alignment during landings and avoided excessive knee valgus and hip adduction. Maximum total support moment and the relative distribution of that moment among joints were also comparable. Both male and female dancers demonstrated an internal knee abduction moment during landing, which is reflective of an external varus moment being applied to the knee and opposite to the loading pattern that has been identified as a predisposing factor to ACL injury.[9]

Previous research has shown that female athletes undergoing plyometric and balance training demonstrated a more neutral lower extremity alignment during landings.[1,17] As female athletes display dangerous landing biomechanics following maturity,[5,8,22] these training programs are often targeted toward older athletes, usually in high school or college. Although these training techniques have had positive effects on landing biomechanics[1,17] and have been reported by some to reduce subsequent season ACL injury rates,[7,18] it is not known how long these effects last and if continued routine maintenance is needed or whether they lead to decreased knee injury rates over the course of a full athletic career. We speculate that the lack of gender-related landing differences in male and female dancers may be due to the combined effects of training and experience. In

TABLE 3
Sagittal and Frontal Plane Joint Kinetics [means (SD)] during 30-cm Drop Landing[a]

	Sagittal Plane			Frontal Plane		
Joint Moments (N·m/kg)	Ankle Plantar Flexion (+)	Knee Extension (+)	Hip Extension (+)	Ankle Inversion (+)	Knee Adduction (+)	Hip Abduction (+)
Initial contact						
Males	0.2 (0.1)	–0.4 (0.1)	0.5 (0.3)	–0.002 (0.04)	0.02 (0.1)	–0.1 (0.1)
Females	0.2 (0.1)	–0.4 (0.2)	0.6 (0.8)	0.01 (0.05)	–0.02 (0.1)	–0.2 (0.4)
Max knee flexion						
Males	1.2 (0.3)	1.6 (0.5)	1.0 (0.7)	–0.01 (0.01)	–0.6 (0.3)	1.3 (0.4)
Females	1.1 (0.3)	1.4 (0.5)	0.8 (0.6)	–0.07 (0.2)	–0.4 (0.4)	1.0 (0.5)
Peak during landing						
Males	2.1 (0.4)	3.1 (0.8)	4.0 (1.3)	0.3 (0.2)	–1.7 (0.4)	3.0 (0.9)
Females	1.8 (0.3)	3.2 (0.7)	3.7 (1.7)	0.4 (0.2)	–1.5 (0.4)	3.0 (0.8)

[a]Data shown as means, with standard deviation in parentheses. Multivariate analysis of variance revealed no significant difference between genders ($P = .175$).

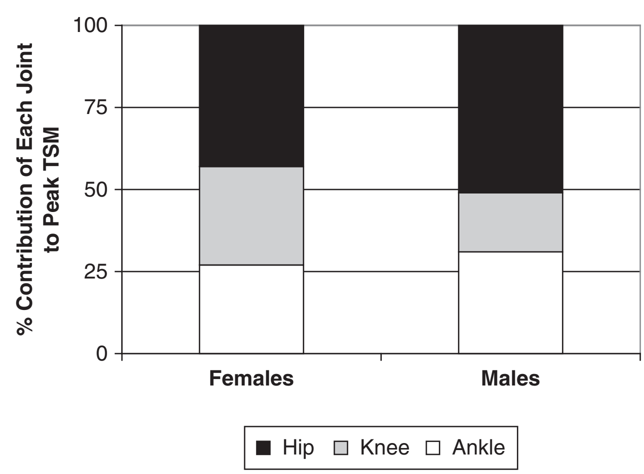

Figure 3. Comparison of maximum total support moment (TSM) and joint contributions between genders. No difference in peak total support moment was found between male and female dancers ($P = .505$). Individual contributions of the ankle, knee, and hip to the peak total support moment were not different between genders (multivariate analysis of variance, $P = .175$).

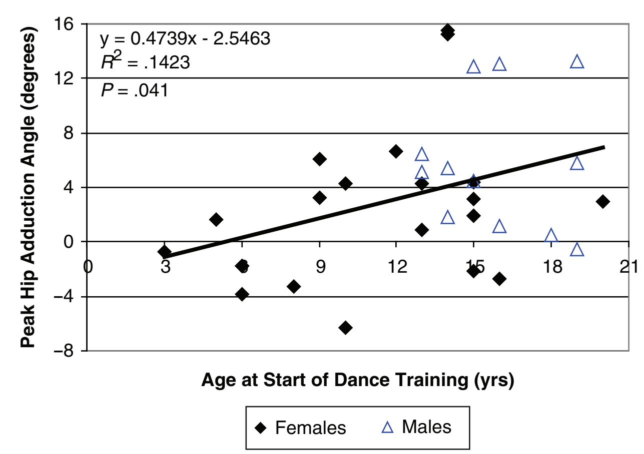

Figure 4. Correlation between peak hip adduction during landing and the age at which dance training began. Pearson correlation revealed that dancers who began training at a younger age were able to limit hip adduction during landing ($r = .358$, $P = .041$).

contrast to other athletic disciplines, dancers are trained in jumping and balance from their first steps into the studio, and they constantly practice and perfect these techniques throughout their careers. Our study demonstrated that dancers who started training as children demonstrated better control of hip adduction than those who began training in their teenage years. Therefore, training in proper landing technique from an early age may diminish the negative adaptations in landing biomechanics associated with maturation in female athletes.

Male and female dancers appeared to use a hip-dominant strategy to avoid injurious lower extremity landing patterns. In the sagittal plane, the hip accounted for about 50% of the peak total support moment and the peak hip extension moment generated during landing averaged about 4.0 N·m/kg for both groups. The use of this strategy did not appear to reduce vertical ground-reaction forces in comparison with recreational athletes performing a similar task.[13,16] Studies by Lephart et al[13] and McNitt-Gray[16] showed similar peak vertical ground-reaction forces for recreational athletes performing drop landings from heights of 20 and 32 cm, respectively.

Although the dancers in this study did not exhibit reduced ground-reaction forces compared with other athletic populations, they did exhibit greater landing phase durations. Previous research has shown average landing phase durations for recreational athletes to be about 130 to 180 milliseconds.[13,16] By comparison, average landing phase duration for the dancers in this study was about 260 milliseconds. Additionally, McNitt-Gray[16] found similar landing phase durations in collegiate gymnasts (about 300 milliseconds). Therefore, although dancers did not exhibit lower peak ground-reaction forces, they generally attenuated landing force over a longer period of time. Thus, the ability to control the dissipation of impact forces may help this population avoid serious lower extremity injuries.

The large peak hip abduction moment (about 3.0 N·m/kg for both males and females) generated by both groups most likely explains the minimal excursion into an adducted hip position (4.8° ± 5.3° for the men; 0.9° ± 5.4° for the women) by the end of the landing. This gives further credence to previous research highlighting the importance of having adequate frontal plane hip control for the prevention of serious knee injuries.[2,11,20,29] Previous studies have reported maximum hip adduction angles in male athletes during single-legged landings to be in the 5° to 10° range, whereas peak hip adduction in female athletes has been observed to be 10° to 13°.[6,11,13] The current data seem to indicate that dancers are able to limit frontal plane hip range of motion (hip adduction angle at maximum knee flexion: males, 4.8° ± 5.3°; females, 0.9° ± 5.4°) through enhanced neuromuscular control and positioning of neighboring joints. As evidenced by the relationship between peak hip adduction angle during landing and the age at which our participants began dance training, this enhanced control can, in part, be attributed to learning and practicing proper technique from an early age.

Dancers in this study exhibited less variability in the patterns of their landings as compared with athletes. Practicing landing strategies over a long period of time could be responsible for the relatively low variance in frontal plane hip biomechanics displayed in this population compared with other athletic populations. Kernozek et al[12] reported standard deviations between 46% and 87% for frontal plane hip range of motion in recreational female and male athletes performing drop landings from a 60-cm height. The same study also reported standard deviations of 48% and 66% for frontal plane internal hip moments. In contrast, the current population of professional dancers displayed standard deviations of approximately 33% for hip adduction/abduction range of motion and 25% to 30% for hip adduction/abduction moments. Thus, as a result of extensive practice and training, dancers are able to more consistently control joint motion and moments from one landing to the next to avoid any unanticipated internal perturbations that may result in injury.

Limitations

The comparable means and well-matched standard deviations of our groups seem to indicate that the lack of differences between groups was not due to low statistical power. For the kinematic and kinetic variables examined, power analysis indicated that the total number of participants required to detect a difference with 80% power and the α level at .05 ranged from 140 to 12 000, with effect sizes for these variables ranging from 0.24 to 0.005. There were similar results for peak total support moment (400 participants for 80% power, effect size 0.16) and peak vertical ground-reaction force (100 participants needed, effect size 0.24). Thus, we are confident that the lack of statistical significance in this study was due to no real difference in the landing mechanics between male and female dancers in this task rather than to lack of statistical power. Another potential limitation to this study was the fact that participants wore their own personal athletic shoes during the testing protocol as opposed to performing the landings barefoot. Although the differences in footwear between participants could have affected the ground-reaction force measurements, we decided that wearing shoes during the testing best allowed for comparison of the results of the present study with data from other athletic populations.[5,21,22]

Further work in this area should examine the biomechanics of unexpected landings in this population. As ACL injuries typically occur when trying to recover from an unexpected situation and dance activities are usually tightly choreographed,[14] it is possible that previously reported high-risk gender differences in landing mechanics may appear in these situations. Comparing young athletes with young dancers may also give insight as to when the gender-specific adaptations during landing occur, as it is possible that dancers with fewer years of training may still exhibit landing biomechanics that predispose to ACL injury. Additionally, prospective biomechanical-epidemiologic studies would eliminate selection bias that may exist in biomechanical studies of injury-free dancers or athletes.

CONCLUSION

This study found no difference in lower extremity landing biomechanics between male and female professional dancers. Through many years of continuous jump-specific and balance-specific training, both groups developed a hip-dominant strategy that may protect them from serious lower extremity injuries. These results seem to indicate that, in contrast to dance groups, the commonly reported biomechanical differences between male and female athletes, as well as the gender disparity among athletes in the incidence of ACL injuries, may result from inadequate experience in proper balance and landing technique rather than factors attributable specifically to gender. Beginning jump-specific and balance-specific training at an early age may counteract the potentially harmful adaptations in landing biomechanics observed in female athletes following maturity.

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