Original Research

Biomechanics and Proprioceptive Differences during Drop Landings between Dancers and Non-Dancers

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ABSTRACT

International Journal of Exercise Science 6(4) : 289-299, 2013. The focus of this research was to determine if female dancers have differing kinematic and kinetic characteristics when landing from three heights (0.2, 0.5, and 0.8 m) both with and without vision compared to non-dancers. It was hypothesized that dancers would show differing kinematic and kinetic patterns of control due to their increased proprioceptive awareness. Eight collegiate dancers and seven collegiate controls who were neither dancers nor collegiate jumping athletes volunteered for this study. Sagittal plane lower limb joint angles were measured at 100 Hz prior to landing through stability with a high-speed camera, and peak vertical ground reaction forces relative to body weight were recorded with an indwelling force plate. Results indicated biomechanical differences across height and vision conditions, as well as between groups. Kinetic results showed a significant height effect with respect to vertical ground reaction forces. From the 0.8 m drop, both dancers and non-dancers produced significantly greater ground reaction forces when landing without vision compared to when they landed with vision. No significant kinetic differences were found between groups. Kinematic results revealed a significant height effect for the hip and knee angles across groups and vision conditions, meaning that as drop height increased, the participants demonstrated greater range of motion in their hip and knee joints. Dancers and non-dancers responded differently when dropping from 0.8 m without vision. Dancers significantly increased hip flexion compared to landing with vision, while non-dancers tended to stiffen up and reduced hip flexion. These findings suggest that dancers utilize proprioceptive input more effectively as they adopted a hip strategy (flexion of the hips) to maintain stability. Training dancers without vision may impact dance instruction and reduce the risk of injuries when landing.

KEY WORDS: Drop landing, dancers, proprioception

INTRODUCTION

Professional dancers, particularly those involved in ballet and modern companies or Broadway shows, are at risk for injuries due to the high degree of repetitive movement. The incidence of injury within professional modern and ballet companies ranges from 17% to 95% each season (23). However, the patterns of injury between companies remain fairly consistent with overuse injuries to the lower extremity being the most common (i.e. tendonitis, stress fractures) (10, 22). The cause of this high prevalence of overuse injuries in dancers varies, but landing mechanics is likely a main contributor because of the repetitive requirement of the legs to absorb landing forces by eccentrically contracting muscles as joints flex (17). The most common traumatic injuries in dancers are ankle inversion injuries, which are often the result of improper jump landings (13).

Some studies have also found differences in kinematics and kinetics of landings between genders because of anthropometrical and anatomical differences such as the angle between the pelvis and the knee (Q-angle) and related forces in females (3, 14). It is suspected that these differences contribute to the uneven injury rate between males and females. It is well documented that women have a higher anterior cruciate ligament (ACL) injury rate compared to men, and studies have shown that the ACL injury rate for females is up to eight times higher than that for males and may be a result of altered landing strategies (3, 5, 6, 20, 32). Given these different rates of injury between genders, only female participants will be used in this research.

The importance of assessing dancers' landing techniques cannot be understated. In classical ballet, proper landing techniques consist of a forefoot landing and bend at the knees or *plié*. This forefoot strategy is beneficial because it reduces shock and absorbs energy that protects bones and joints superior to the site of impact (16). Not only is the aforementioned landing strategy mechanically safe and effective, it also plays a role in the aesthetic nature of dance. It is generally accepted that for a 'soft landing' resulting in little noise is a result of larger joint flexion angles. Dancers are trained to land in this manner not only to reduce injury but to perform silent landings. A dancer could not make the movement appear so graceful and effortless if every landing was highly audible. Ballet dancers wearing pointe shoes are especially aware of this, as this kind of shoe is capable of producing loud sounds during landing movements as a result of the box in the shoe.

Drop landing strategies have a specific kinematic pattern and affect how the body absorbs energy (5). Peak angular displacements occur in a distal-proximal order during landing (29). The chosen foot placement significantly modifies the landing kinematics. The two main strategies utilized by athletes are the forefoot landing and the heel-toe landing strategies. In general, during the flexion phase of landing, the larger the joint flexion angle is, the 'softer' the landing. In a heel-toe landing, the angle displacement of the ankle is less than it is during the forefoot landing strategy, while the hip and knee angular displacements are significantly larger in the heel-toe landing strategy at initial ground contact (5, 16). In a forefoot landing, the ankle and knee joints are in an optimal position for deceleration and require the individual to maintain a more erect position (29). This erect posture is determined by the degree of trunk flexion. Blackburn and Padua (1) found that active trunk flexion during landing produced increases in both the knee and hip flexion, compared to an extended trunk posture. Previous research has found that larger knee and hip flexion angles correspond to a reduced risk of ACL injury (1). Since females are at a heightened risk for this injury, examining hip and knee flexion angles upon landing is imperative. In addition, landing technique is highly influenced by training, and skilled and unskilled subjects have demonstrated kinematic differences between landings (21). Lastly, an influencing factor on landing kinematics that has been extensively studied is the height from which the subject drops. Generally, there are increases in biomechanical responses to increases in landing heights (29, 33).

In addition to kinematic factors, kinetic analyses concerning drop heights are imperative. Numerous studies have used force plates to collect Ground Reaction Force (GRF; F_z) data, as increased GRF can be associated with injuries, particularly those affecting the knee joint (8). The accumulation of high impact forces can threaten the integrity of the lower extremity overtime and contribute to overuse injuries (33). Previous studies have also found that impact forces decrease with increasing knee flexion, so this strategy should be adopted to prevent injuries (8). Increased drop heights have been correlated with increased peak impact forces (21, 28, 29). Reaction forces also correlate to landing foot placement and strategy, with peak impact force being 3.4 times greater in heel-toe landing than in the toe-heel landing (16, 17, 33).

While numerous studies have investigated the effects of foot placement, gender, and technique on landings, only a few have addressed proprioceptive mechanisms during landings by taking away vision. Proprioception is the ability to perceive where one's body is in space and how one's body segments relate to each other (15). This is accomplished by sensory receptors in the joints and muscles. Consequently, proprioception provides feedback concerning posture and aids in stability, balance, and coordination. Coordinated movement is achieved by sensorimotor integration, which includes feedback from proprioceptive, vestibular, and visual sources. Vestibular input while important, is not easy to systematically manipulate and thus is assumed to be stable in postural control and landing research (15, 29). Visual input is important during locomotion and during drop landings because it provides information about the upcoming events and surrounding environment (2, 27, 31). Some researchers have shown that with repetition the reliance on vision decreases (19, 29), thus with extensive practice individuals may be able to switch to a more proprioceptively controlled landing. No research to our knowledge has attempted to analyze landing differences between a skilled and unskilled group in the absence of vision. It has been shown that visual input is the preferential afferent among dancers during balance tasks, and when the eyes are closed, postural control is governed by vestibular and proprioceptive mechanisms (12). Furthermore, it has been shown that professional dance training may shift sensorimotor mechanisms from reliance on vision to proprioception in well-practiced balance tasks (9).

As a result, further investigation into the use of proprioceptive mechanisms by dancers in a landing task is warranted. The purpose of this research was to compare drop landings of three heights between dancers and non-dancers with and without the use of vision. By measuring joint angles in the sagittal plane and vertical GRFs , both kinematic and kinetic analyses were considered. It was hypothesized that significant biomechanical differences would result between the two groups of subjects and across the two vision conditions. Specifically, dancers would be less affected by the absence of vision during their landings than the untrained subjects. They would demonstrate greater flexion/extension range of motion in hips and knees compared to non-dancers. Additionally, it was hypothesized that dancers would produce smaller peak vertical GRFs compared to non-dancers due to their predicted toe-heel landing strategy. This would suggest dancers are likely able to use proprioceptive input more effectively than non-dancers.

METHODS

Participants

A convenience sample of eight collegiate dance majors with ballet as a specialty was gathered from Elon University's Department of Performing Arts. Likewise, a sample to serve as the non-dancers consisted of seven students enrolled at Elon University, all of whom were neither dancers nor collegiate athletes. All of the dancers had at least eight years of formal ballet dance training with an average amount of fourteen years of experience. The non-dancers were recreationally active but lacked experience in landing sports such as basketball, volleyball, and track and field. The mean age of the dancers was 20.5±1.2 years, while the mean age for the non-dancers was 20.9 ±0.38 years. There were no significant demographic differences between groups ($p>0.05$; Table 1). Before testing, all participants signed an informed consent form, which was approved by both the Elon University IRB and the Alamance Regional Medical Center IRB. Each participant received a compensation of five dollars for this study.

Protocol

Instrumentation for this research consisted of an indwelling force plate (AMTI, Watertown, MA) with a 1000 Hz sampling frequency, a high-speed video camera (Southern Vision Systems Inc., Madison, AL) that recorded trials at 100 Hz, joint markers for kinematic analysis, and Hu-m-an^tm Movement Analysis software (HMA Technology, Guelph, Ontario). The force plate was used to record vertical GRFs (F_z) upon the subjects' landings, while the joint markers and video camera were used to analyze the range of the joint angles in the sagittal plane from take-off to landing. Hu-m-an^tm Movement Analysis software was used to digitize the kinematic data.

Table 1. Participant Characteristics.

	Dancers (n=8)	Non-Dancers (n=7)	Total (n=15)
Mean Age (SD)	20.5 (1.2)	20.9 (0.38)	
Mean Height (cm) (SD)	162.7 (7.26)	166.4 (4.08)	
Mean Weight (N) (SD)	558.8 (80.8)	580.81 (50.9)	
Dance Training (yrs) (SD)	14.4 (3.1)	0	

The procedures for testing were the same for both dancers and non-dancers. Testing was conducted in the Center for Fitness and Human Movement Studies at Alamance Regional Medical Center. Upon entering the facility, the participants read and signed the informed consent form. They also filled out a questionnaire, which contained both medical history and physical activity-related questions before participating in order to verify their safety, as participants with chronic lower extremity injuries were excluded. Reflective joint markers used for kinematic analysis were placed on the pre-determined landmarks and joints along the right side of the body for each subject (sagittal plane, dominant side). These included the iliac crest, greater trochanter, femoral lateral epicondyle, lateral malleolus, lateral calcaneus, and base of the fifth metatarsal. The barefooted subjects were instructed to step from the platform and land with both feet on the force plate simultaneously. They were not instructed to land on forefoot or heel-toe, but landing preference was recorded. Protocol set-up did not allow for participants to land with one foot on the force platform, but kinematic recordings were conducted on their dominant side. Participants were told to place their arms across their chest and to extend them to the side if needed when landing, as to not block any of the reflective joint markers. They were given an opportunity to practice the multiple drops prior to data collection at each height in order to feel comfortable with experimental protocol. The subjects then performed drop landings from three different heights (0.2 m, 0.5 m, 0.8 m), landing onto the force plate with the right side of the body facing the camera for data collection. Four successfully performed trials from each height were included in the analyses, two for eyes open and closed, which were averaged respectively. Due to the height of the box, we did not want to fatigue subjects with multiple trials. All the jumps were self-initiated. There were six conditions during the experiment, which were randomized between subjects and blocked within subjects. The six conditions were 0.2 m vision, 0.2 m no vision, 0.5 m vision, 0.5 m no vision, 0.8m vision, and 0.8m no vision. This meant that if a subject was randomly assigned to the order of 0.2m, 0.5m, 0.8m, the subject would drop from each height with eyes open and eyes closed two times (alternating between vision and non-vision depending on what they were randomly assigned to) before proceeding to the next height. The data was collected in one session, which lasted approximately thirty minutes for each subject.

Statistical Analysis
Kinematic data (knee, hip and ankle angles in the sagittal plane) were filtered with a 2nd order low-pass Butterworth filter with a cut-off 10 Hz. Peak values of GRF (F_z) as a percentage of body weight for each trial were recorded. Landing preference (forefoot or heel-toe) was recorded as well as if they landed on one foot. Statistical analyses of the data were conducted to determine the significance of the results with an alpha value of 0.05. A repeated measures 3 (heights) x 2 (groups) x 2 (vision conditions) MANOVA was performed in SPSS 16.0 for Windows.

RESULTS

The ranges of joint flexion and extension were compared between groups and across height and vision conditions. Results showed a significant Joint Effect ($F_{(2,26)}=51.22$, $p<0.001$), and post hoc analysis found significant differences across all joints ($p<0.01$) with the knee having the largest range of motion followed by the ankle and lastly, the hip. There was also a significant Height Effect ($F_{(2, 26)}=36.18$, $p<0.001$), and post hoc analysis showed significant differences between all three heights ($p<0.01$). However, there was also a significant Height x Joint Interaction ($F_{(4, 52)}=29.00$, $p<0.001$) which found that the ankle joint range of motion stayed constant across height increases, while the hip and knee joints increased range of motion across heights. No other main effects or interactions reached significance ($p>0.05$).

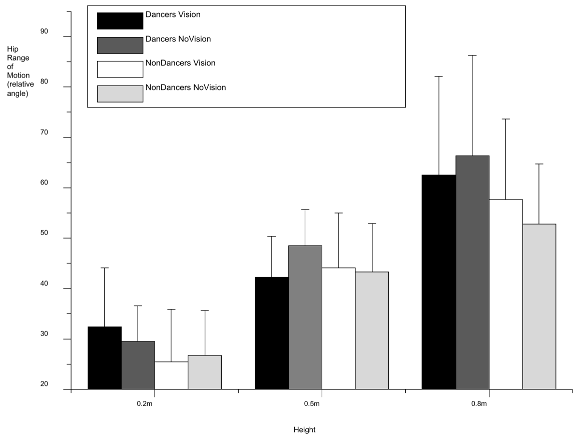

Figure 1. Hip range of motion. The average hip range of motion illustrated across three heights, two vision conditions, and between two groups. Significant Height Effect ($p<0.001$) shown as well as Height x Vision x Group Effect at 0.8 m ($p<0.05$).

Each joint was analyzed separately to determine if individual joints followed certain patterns, without the consideration of other joints, across height and vision conditions. For the hip (refer to Figure 1), there was a significant Height Effect ($F_{(2,26)}=42.84$, $p<0.001$), with hip range of motion in the sagittal plane increasing across heights. A Height x Vision x Group Effect was also observed ($F_{(2,26)}=4.00$, $p<0.05$). Range of motion among dancers increased in the no vision condition, whereas it decreased among non-dancers. No other main effects or interactions reached significance ($p>0.05$).

For the knee angle, a significant Height Effect was found ($F_{(2,26)}=27.60$, $p<0.001$), with knee range of motion increasing across the three heights, as shown in Figure 2. No other significant effects were observed for the knee joint ($p>0.05$).

Unlike the hip and knee joints, there was no Height Effect found for the ankle ($p>0.05$), as the ankle joint range of motion remained constant across the three heights (Figure 3). There were no other significant effects for the ankle joint ($p>0.05$). In addition, all subjects landed with a heel-toe strategy across trials and no subjects landed on one foot.

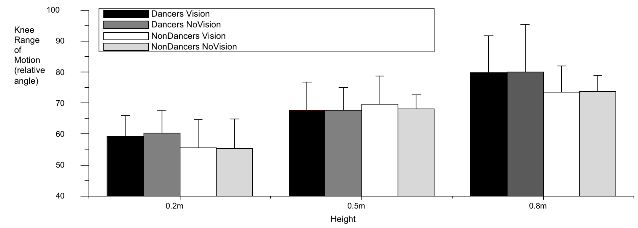

Figure 2. Knee range of motion. The average knee range of motion illustrated across three heights, two vision conditions, and between two groups. Significant Height Effect ($p<0.001$) shown.

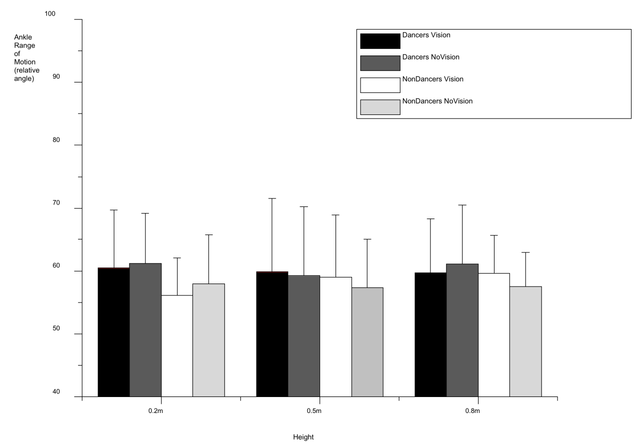

Figure 3. Ankle range of motion. The average ankle range of motion illustrated across three heights, two vision conditions, and between two groups. No significant effects found ($p>0.05$).

As expected, results showed a Height Effect ($F_{(2,26)}=85.3$, $p<0.001$), as vertical GRFs (F_z) significantly increased with increases in drop heights. A Height x Vision Interaction was also found ($F_{(2,\ 26)}=7.83$, $p< 0.005$) at the drop height of 0.8 m. This is depicted in Figure 4. From this height, GRFs were significantly larger in the absence of vision than with vision across both groups. No effects reached significance between groups ($p>0.05$).

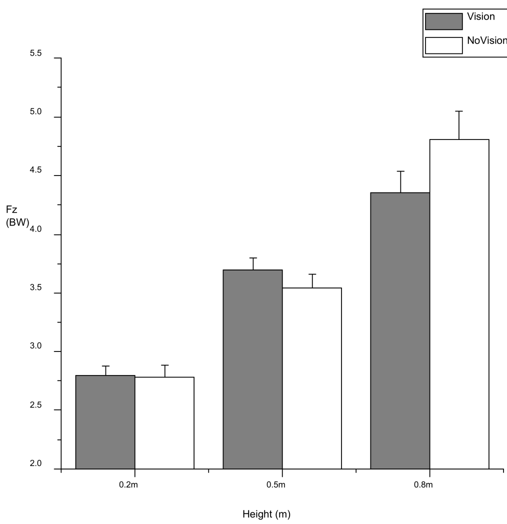

Figure 4. Relative ground reaction force between vision conditions. An illustration of relative GRF (F_z) across three heights and two vision conditions. A significant Height x Vision Effect shown at 0.8 m ($p<0.005$), as relative GRF significantly increased across both groups without vision compared to with vision.

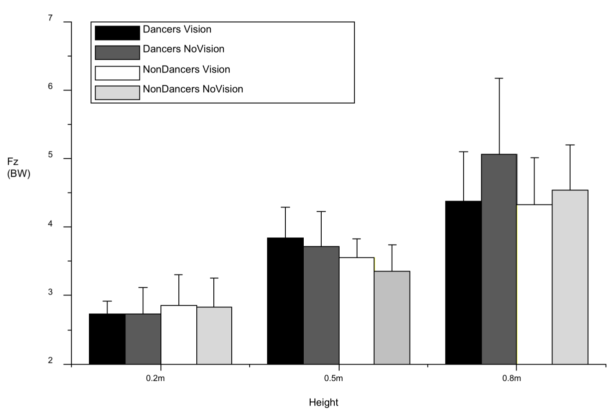

Figure 5. Relative ground reaction force between groups. An illustration of relative GRF across three heights, two vision conditions, and between two groups. A significant Height x Vision Effect shown at 0.8 m ($p<0.005$) as well as a significant Height Effect ($p<0.001$). No significant differences observed between groups ($p>0.05$).

DISCUSSION

The main finding of this investigation was that dancers and non-dancers demonstrated differing kinematic patterns when landing from 0.8 m without vision. Dancers significantly increased their hip range of motion in the sagittal plan, while non-dancers stiffened in their hip joints and significantly decreased their hip range of motion when landing. This difference was only found in trials without vision, therefore proprioceptive differences are likely to account for this result. Formal dance training may enhance the use of proprioceptive and kinesthetic cues (9). This has been shown in research examining differences in balance and postural control between professional dancers and controls (9). According to this study, the same logic holds for landings. Decreases in joint flexion are associated with 'stiff' landings (9). The proprioceptive input for dancers reversed this strategy, as dancers increased hip flexion and therefore utilized a hip strategy to maintain stability during landing. Zhang and colleagues (33) found that a hip strategy was associated with 'soft' landings, as opposed to 'stiff' landings. Dancers are trained to appear graceful and consequently are trained to land softly, their use of the hip strategy may be a direct result of their training. Dancers may also be better suited than non-dancers to adopt this strategy because of the hypermobility of their joints (11). This technique is effective not only because it is associated with soft, stable landings, but increased hip flexion has been associated with reduced knee injuries as well, including a decreased risk for ACL injury (1, 5). This strategy was amplified among dancers in the absence of vision, demonstrating greater proprioceptive and vestibular mechanisms, as the hip strategy is indeed an effective technique. A study by Simmons (30) likewise found that only dancers and not controls utilized a hip strategy to maintain balance when somatosensory information became unreliable. The similar findings of the present investigation establish that dancers do rely heavily on proprioception and sensorimotor cues, perhaps to a greater extent than controls.

The hip strategy is used in order to achieve a rapid stabilizing of the center of mass, and it appears only if vestibular information is intact (26). The vestibular system consists of three semicircular canals in the inner ears, which are gravity receptors that provide information to the central nervous system about the linear and angular accelerations of the body. Vestibular information is also used to provide stable visual input and gaze control (4, 7). From the results of this investigation, one may infer that because only dancers utilized the hip strategy in the absence of vision, there were no disturbances in their vestibular information, unlike the non-dancers. While measurements of head displacement were not taken, it appears that dancers stabilized their head movements during landing in order to protect their vestibular system, as the dancers were more likely to reach stability upon landing than the non-dancers. A qualitative analysis of force plate data was conducted to determine if participants regained stability. This was measured by identifying if F_z data was equal to weight. According to this rough estimation of regaining stability – 87.5% of dancers regained stability upon landing while only 42.9% of non-dancers did. This suggests that non-dancers might not have stabilized their head when vision was lacking, which could explain why they did not adopt the effective hip strategy upon landing. Since dancers are typically trained to hold their gaze outward to the audience during landing and not downward, this finding may be attributed to their skill and experience. However, a future study that investigates head displacement in addition to lower body kinematics would be beneficial to provide evidence for this theory.

Dancers' training may have influenced these results in other ways as well. Oatis (24) suggested that the muscles acting on the toes and feet play a major role in stabilizing posture in barefooted subjects. The ability to use vision or proprioception is influenced by the presence and accuracy of ankle and foot sensory cues (9). Cutaneous or pressure receptors in the feet provide the orientation of the body with respect to the ground and also provide information about ground reaction forces. Dancers, particularly the participants in this study, often train barefooted. All participants in this study completed the trials barefooted, this may have placed dancers at an advantage over the controls and could explain why they utilized more effective proprioceptive mechanisms during landings.

Kinematic results also showed that hip and knee joint range of motion in the sagittal plane increased as drop height increased. This was expected, as increasing joint flexion from increasing heights has been verified throughout the literature (1, 16, 21). Interestingly, no significant differences were found for the ankle joint range of motion across heights. McNitt-Gray (21) found similar results when testing gymnasts, as it was observed that the minimum angle of ankle flexion was reached at all drop heights. This study supports such findings. Additionally, no difference in ankle flexion was found between groups, which are likely explained by the similar landing strategy used by dancers and non-dancers. It was hypothesized that dancers would utilize the forefoot or toe-heel landing technique, which did occur, but the non-dancers utilized this strategy as well. This could account for the similarities between groups.

The main kinetic finding in this study was the Height x Vision Interaction at 0.8 m across both groups. Without vision, both dancers and non-dancers demonstrated significantly greater GRFs upon landing at 0.8 m than with vision. Santello and colleagues (29) found that GRFs were up to ten times larger for landings without vision, as compared to landings with vision. However, the participants from that study were unable to view the drop height prior to the fall, unlike this present investigation. Liebermann and Goodman (18) assessed GRFs from drop heights ranging from 0.05 to 0.95 m. These researchers found that being able to view the environment and height of the drop prior to initiating the fall without vision provided enough feedback to compensate for the lack of vision. The authors concluded that visual guidance during a fall is not necessary if the environmental cues are seen beforehand. Their results did not show significant differences in GRFs between vision conditions. The present investigation, however, did find significant differences only at 0 .8 m. Santello and colleagues (29) attributed the greater GRFs when landing without vision to increased stiffness of joint rotations. This notion could be applied to the non-dancers, for they decreased hip range of motion in the absence of vision when dropping from 0.8 m. Yet because the increased GRFs were observed across both groups, other explanations are plausible, including differences in experimental designs. Unlike the present investigation, the subjects in the study by Liebermann and Goodman (18) performed six trials from each height under both vision conditions. Given this profound difference, the participants in this investigation never became accustomed to landing from 0.8 m. Also, 0.8 m is greater than what is typically encountered during landings in daily living, it is possible that performing only two trials with eyes closed is not enough for subjects to adapt to the height. As a result, GRFs were increased upon impact due to slight motor control changes.

Interestingly, no significant differences were found between groups. Because GRFs are correlated to landing technique, the same landing strategy (forefoot) adopted by both dancers and non-dancers can explain the similarities between groups. Lastly, as GRFs are also correlated to drop height, GRFs increased as drop height increased, as expected.

The implications of this research are significant. The field of dance medicine and research has grown tremendously over the last decade, and additional knowledge that provides insights for training and injury prevention is worthwhile. Because this investigation found significant differences in landing strategies between dancers and non-dancers, with dancers using proprioceptive input more effectively, this stresses the importance of incorporating appropriate proprioceptive training into dance instruction. Interestingly, dancers are trained to maintain vertical alignment during jumps, but by demonstrating the hip strategy, they shifted towards proprioceptive and sensorimotor input in order to land safely, regardless of their alignment training, which has been supported in previous research (25). Such a strategy is important for stability, and the dancers were able to compensate well. Dancers who are able to effectively utilize proprioceptive input are less likely to suffer from injuries while landing. Since most traumatic dance injuries are a result of improper landings, the use of proprioception across dance training is imperative.

Future research should investigate more natural dancing landings. This study involved limited number of landings and from a static height drop. Dancers usually land multiple times and if drop from a height of 0.8m it is as a part of a dynamic movement. In addition, assessment of kinematics and kinetics of each leg may provide additional information that would be useful in training of dancers if there are imbalances across legs.

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