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Original research

Dance floor force reduction influences ankle loads in dancers during drop landings

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ABSTRACT

Objectives: Dance floor mechanical properties have the potential to influence the high frequency of ankle injuries in dancers. However, biomechanical risk factors for injury during human movement on hard, low force reduction floors have not been established. The aim of this study was to examine the ankle joint mechanics of dancers performing drop landings on dance floors with varied levels of force reduction.
Design: Repeated measures cross sectional study.
Methods: Fourteen dancers performed drop landings on five custom built dance floors. Ankle joint mechanics were calculated using a three dimensional kinematic model and inverse dynamics approach.
Results: Ankle joint kinematic (dorsiflexion; range of motion, peak angular velocity and acceleration) and kinetic (plantar flexion; peak joint moments and power) variables significantly increased with a decrease in floor force reduction. Many of the observed changes occurred within a latency of <0.1 s post-contact with the floor and were associated with increased vertical ground reaction forces and decreased floor vertical deformation.
Conclusions: The observed mechanical changes are interpreted as an increase in the load experienced by the energy absorbing structures that cross the ankle. The short latency of the changes represents a high intensity movement at the ankle during a period of limited cognitive neuromuscular control. It is suggested that these observations may have injury risk implications for dancers that are related to joint stabilization. These findings may be of benefit for further investigation of dance injury prevention and support the notion that bespoke force reduction standards for dance floors are necessary.

1. Introduction

The floors used by dancers may influence dance injuries,[1–3] but supporting evidence is limited. Dancers are susceptible to a high injury frequency, particularly at the ankle.[4–6] Dancer injuries are likely the result of the loading frequency and intensity associated with dance training.[6,7] Many dancers spend over 40 h per week training on dance floors,[5] performing in footwear with limited shock absorbing properties. Dance floors can provide an external source of force reduction (FR) to dancers. Standards for dance floor manufacture are limited[8,9] as it is unclear what levels of FR are required by dancers and if floor FR influences injury risk in dancers.

Biomechanical injury risk factors associated with floor mechanical properties are relatively unknown.[10] In fact, the majority of studies concerning the effects of floor FR on human locomotion report robust lower limb adaptations, where leg stiffness varies inversely to floor stiffness.[11,12] These adaptations have recently been observed in dance landings.[13] Nonetheless, it is a common belief that floor FR is associated with injury.[1,2,10] Therefore, the biomechanical adaptations used by dancers to accommodate floor FR, although robust,[11,12] may be associated with injury risk exposure.

Some of the most common dance injuries are ankle tendinopathies and sprains.[3–5] Tendinopathy is associated with excessive and repetitive loading to the pathological tissues.[14] Achilles tendinopathy is common in individuals such as dancers who perform frequent landing tasks which are associated with successive, intense, eccentric contractions of the triceps surae required to stabilize rapid dorsiflexion at the ankle.[14] Inversion ankle sprains result from an inability of the ankle joint musculature to respond to excessive mechanical demand[15] and can be influenced by the orientation of the foot at contact with the floor.[16] If floor FR is related to common dance injuries, floor FR would affect

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loads at the ankle similar to that associated with tendinopathy and ankle sprains.

During landings, the ankle joint must rapidly accommodate high loads due to the dynamic contact of the foot with the floor.[17] Ankle mechanics during the first 0.1 s of landings have been described as a passive interaction with the floor which are regulated by pre-landing activation of the ankle musculature.[12,18] Co-activation of the lower leg musculature prior to landing increases ankle joint stiffness and the impedance required to stabilize the rapid movement of the foot produced as a result of contact with the floor.[17] Joint stiffness is modified in accordance with the anticipated mechanical properties of a floor,[11] and dancers have a demonstrated ability to perceive changes in floor FR.[9] High mechanical demand or errors in the orientation of the foot may therefore cause excessive tissue stress or destabilize the ankle joint complex during the early stages of a landing cycle. Low or unexpected floor FR may further affect these mechanics due to increased ground reaction forces and decreased floor vertical deformation (VD).

The aim of this study was to examine the ankle joint mechanics of dancers performing landings on a range of dance floors with varied FR. Due to the frequency of injury,[3–5] the loading,[17] and the passive mechanics[12,18] at the ankle joint in dancers during forefoot landings, specific attention was directed toward the ankle joint kinematics and kinetics during the early stages of floor contact. It was hypothesized that dancers performing drop landings on floors of decreasing FR would be associated with an increase in the ankle joint mechanical demand within a short latency from foot contact with the floor.

2. Methods

Thirteen dancers from the Western Australian Academy of Performing Arts (Edith Cowan University, AUS) and one ex-professional dancer with predominantly contemporary and ballet training (males $n = 5$; females $n = 8$; age 20.7 ± 5.1 years; mass 60.9 ± 9.9 kg; height 1.7 ± 0.1 m) performed four landing trials on five custom dance floors with varied FR. Three dimensional kinematics and ground reaction forces were captured during landing trials using 12 Vicon MX cameras (Oxford Metrics, Oxford, UK) at 250 Hz and one AMTI force plate (1.2 m × 1.2 m) (AMTI, Watertown, USA) at 1000 Hz.

FR was used to differentiate the mechanical properties of the floors. FR is calculated as a ratio of the peak force recorded by dropping a mass (The Advanced Artificial Athlete, Metaalmaatwerk, NL; 20 kg attached to a 2000 kN/m stiffness spring) onto a rigid concrete floor compared with the peak force recorded on a test floor.[19] FR is reported as a percentage; a floor with 0% FR would record the same peak force as that of a concrete floor. The floors used in this investigation have been previously reported in Hopper et al.[9] Each floor was constructed from a 1.2 m × 1.2 m plywood board and a series of neoprene pads with varied configurations on the underside of the board. The floor materials are currently used in the manufacture of commercially available dance floors (Harlequin Floors, London, UK). The test floors represented FR values that were below (Floor 1), within (Floors 2 and 3) and above (Floors 4 and 5) the acceptable range specified in the European standards for indoor wooden sports and dance floors (50–70%).[20]

Test floors were placed directly on top of the force plate as performed by Ferris et al.[11] Floors were attached with industrial double sided tape to prevent shifting during landing trials and ensure that the ground reaction forces were entirely captured by the force plate. As accurate center of pressure data were required, the standard vertical offset of the force plate origin was reconfigured due to the potential effect of the floor height on the center of pressure calculations. Pilot testing revealed that a discrepancy of 0.005 m applied to the force plate vertical offset settings resulted in a maximum 4% and a mean 0.01% change in ankle net joint moments throughout a landing task on the outer edge of both a rigid floor and a floor that vertically deformed during landing trials (see supplemental digital content A). The force plate vertical offsets for each trial were configured so that the peak VD of the test floor did not differ from the vertical force plate offset by greater than 0.005 m throughout the trials. Participants also landed on the center of the floors as a further measure to minimize the potential center of pressure discrepancies. Floor VD was calculated as the mean vertical position of three retro-reflective markers placed on the central 0.6 m × 0.6 m square of the floors.

Participants were injury free at the time of the testing, signed a consent form and were given an information sheet disclosing the research design and participant rights, as required by the approval from the University of Western Australia Human Research Ethics Committee. Landing tasks commenced with the participants hanging from a ring suspended above the center of the floors. Landing height for each participant was adjusted so that the distal end of the great toe with the ankle in maximum active ankle plantar flexion was at 0.2 m above the floor surface. Participants were instructed to release their grip of the ring, land on one foot, with the arms maintained above the head. Four landings were performed by each participant on each floor, using their preferred leg. The presentation order of floors was randomized between participants. Participants were provided practice trials on each floor directly prior to the collection of the analyzed trials.

The lower limb marker set and biomechanical model used was developed by researchers at the University of Western Australia, School of Sport Science, Exercise and Health, and although a summary is provided here, Besier et al.[21] outline the method in detail. Twenty two retro-reflective, 0.01 m diameter markers plus four virtual markers, were attached to the pelvis and lower limbs in clusters using double-sided medical grade tape (3M; St. Paul, USA). The marker clusters allowed technical coordinate systems to be established for each lower limb segment during static trials.[22] Subject specific anatomical landmark identification trials identified the positions of medial and lateral femoral condyles with reference to the technical coordinate systems of each segment. Four real markers were also used identify the ankle malleoli. A final subject specific foot alignment calibration trial identified foot and lower leg rotation offsets. All virtual and real calibration markers were used to define standardized anatomical and joint coordinate systems for each participant.

Marker position and ground reaction force data were filtered using a 2nd order low pass Butterworth filter with a cutoff frequency of 10 Hz in Vicon Nexus software (Oxford Metrics, Oxford, UK). The biomechanical model outlined in Besier et al.[21] was used to determine joint axes of rotation and joint centers, facilitating the calculation of relevant segment and joint position data. Segment and joint kinematics (displacements, velocities and accelerations) were then derived and inverse dynamics were used to calculate joint kinetics using the body segment parameters reported in de Leva.[23] Joint moments and powers were expressed as internal moments and normalized to body mass.

Data were analyzed through the ‘initial contact phase’ which was bound by the ‘foot contact’ and the ‘heel contact’ events. Foot contact was identified by the first frame in which a vertical ground reaction force greater than 15 N occurred. The heel contact event was identified by the frame where the marker attached to the calcaneous of the landing leg, reached the lowest vertical point relative to the ground. The mean of the four trials, for each participant, on each floor, for each dependent variable were used in the statistical analyses. Repeated measures ANOVA were used to examine significant effects ($p < 0.05$) of the floors on the data with