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Impact attenuation properties of jazz shoes alter lower limb joint stiffness during jump landings

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ABSTRACT

Objectives: To quantify the impact attenuation properties of the jazz shoes, and to investigate the *in-vivo* effect of four jazz shoe designs on lower limb joint stiffness during a dance-specific jump.
Design: Repeated measures.
Methods: A custom-built mechanical shoe tester similar to that used by athletic shoe companies was used to vertically impact the forefoot and heel region of four different jazz shoe designs. Additionally, dancers performed eight sautés in second position in bare feet and the shoe conditions. Force platforms and 3D-motion capture were used to analyse the joint stiffness of the midfoot, ankle, knee and hip during the jump landings.
Results: Mechanical testing of the jazz shoes revealed significant differences in impact attenuation characteristics among each of the jazz shoe designs. Gross knee and midfoot joint stiffness were significantly affected by the jazz shoe designs in the dancers' jump landings.
Conclusions: The tested jazz shoe designs altered the impact attenuating capacity of jump landing technique in dancers. The cushioned jazz shoes are recommended particularly for injured dancers to reduce impact on the lower limb. Jazz shoe design should consider the impact attenuation properties of the forefoot region, due to the toe-strike landing technique in dance movement.

1. Introduction

Dance performance and practice features highly repetitive loading; however, the implementation of periodization throughout the calendar year or performance schedule to allow adequate recovery is rare.[1,2] Combining this with a culture that promotes "dancing through pain" to ensure opportunities are not lost[3] could potentially put dancers at a greater risk of injury. Proper selection of footwear has the potential to attenuate impact forces transmitted into the body.[4] Despite dancers performing approximately 200 jumps per 1.5 h class each day,[5] the impact attenuation properties of dance shoes have not been quantified.[6] The relationship between the impact attenuating characteristics of shoes and injury risk is not yet fully understood, however, several studies have shown that shoe design has the potential to reduce impact-related injury risk.[7–9]

Athletic shoe testing has shown that various midsole materials are capable of attenuating impact.[9] Investigations into the biomechanical characteristics of weight bearing activities when wearing shoes compared to bare feet yield a variety of results.[4] It has been found that changes in muscle activation occur in response to shoe cushioning prior to ground contact[10] due to the perception of the hardness of the landing surface,[11] and greater impact force when landing on a soft surface during gait and drop landings was due to the body allowing the landing surface to dissipate the impact as opposed to requiring the body to absorb the impact.[12] Furthermore, a study found reduced ankle joint mechanical demand with reduced hardness of dance floors.[13] However, running shod compared to barefoot showed no difference in ankle or knee joint stiffness values.[14] Joint stiffness can also be modified by changing foot strike pattern during gait.[15] Inconsistent effects of cushioning could be a result of the variability of the human response to cushioning in conjunction with the mechanical properties of the shoe.

In dance jump technique, the feet and ankles must be plantar flexed in the air with toe strike at initial ground contact, while between jumps the feet remain flat on the floor during the half-squat (*demi-plié*).[16] To maintain the requisite dance aesthetic of ease of movement and weightlessness, jump landings should be quiet and controlled. The common instruction to dancers is to "roll through the balls of the feet" and to "lift up when landing" to emphasise the control of the landing and appearance of

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Table 1
Description of shoe conditions.

Shoe name	Brand/name/number	Description
Barefoot	N/A	Control condition
Elastabootie 	Bloch Elastabootie S0499L	Slim line leather jazz shoe with separate forefoot and rearfoot sections (split sole design). 3.5 mm forefoot 13 mm rearfoot thickness
Evolution 	Bloch Evolution Dance Sneaker S0510	Split sole design low profile jazz sneaker. Multi-density rubber outsole and additional divisions in the forefoot section. Air punched compressed EVA sock material. 14 mm forefoot and 20 mm rearfoot thickness
Boost 	Bloch Classic Boost S0538L	Split sole design jazz sneaker with thick multi-density rubber outsole and compressed EVA sock material. 24 mm forefoot and 38 mm rearfoot thickness
Chorus 	Bloch Cabaret S0306	50 mm high heel court shoe with ankle strap

weightlessness.[17] Correct technique is thought to be facilitated through eccentric control of metatarsophalangeal and ankle dorsiflexion, and knee and hip flexion.

There is a large variety of jazz shoe designs available and many long-held common beliefs on the contribution of dance shoe design to performance and injury risk.[18,19] Rather than simply applying the findings of athletic shoe research to dance footwear, investigations must be dance-specific in order to draw appropriate conclusions. Research exploring the effect of dance footwear is sparse in comparison to athletic footwear.[6] The primary aim of this study was, therefore, to quantify the impact attenuation characteristics of different designs of jazz shoes using a mechanical testing rig. We hypothesised that the jazz sneaker, with more cushioning and a thicker outsole, would have greater impact attenuation capacity. A secondary aim of this study was to investigate the effect of different jazz shoe designs on dancers' joint stiffness during a dance jump landing. Knee joint stiffness was hypothesised to be greater in the more cushioned shoes.

2. Methods

Four jazz shoe designs were selected for testing, three with a split-sole design (separate forefoot and rearfoot outsoles) and one high-heeled design (Table 1). Impact attenuation properties of the shoes were measured in a custom mechanical impact rig according to the design and protocol outlined in F1614.[20] The impact rig dropped a flat bottomed mass of 8.5 kg to land with a kinetic energy of 5 J. New specimens of the Elastabootie, Evolution, Boost and Chorus jazz shoes (Bloch, Australia) were prepared and tested with five impacts at the forefoot region and five impacts at the heel region of each shoe. Following standard protocol, the variables analysed were: peak force, maximum displacement of the mass in the sole of the shoe, total impact time, hysteresis energy ratio (HER), and normalised average stiffness.[20] The mean energy applied to the shoe specimens was 4.8 ± 0.4 J, which conformed to standard protocol.[20] Repeated measures ANOVA's were used to determine the effect of shoe condition on each variable with level for significance set at $p < 0.05$.

Sixteen female dancers (mean age: 25.0 ± 5.9 years, mean mass: 56.0 ± 7.4 kg) volunteered for the *in vivo* study. All participants were required to have attained a minimum of Royal Academy of Dance (RAD) Intermediate syllabus standard, or equivalent, to ensure consistent and proficient technique execution. Dancers were excluded if they had a current injury that reduced their class or performance participation. All participants gave informed consent; the study is in accordance with the National Statement on Ethical Conduct in Human Research (2007) issued by the National Health and Medical Research Council (NHMRC) in accordance with the NHMRC Act, 1992 (Cth), and was approved by the institutional Human Research Ethics Committee (reference number: 2012/467).

3D motion analysis of 35 markers placed on bony landmarks on the pelvis and lower limbs was used to capture the dance movement.[21] Marker locations were used to define the segments and calculate the joint centres.[22] The task was performed in each of the five shoe conditions (barefoot, three split sole jazz shoe designs of increasing outsole thickness, and the high heeled shoe) in a randomised order (randomization.org), with time allowed for familiarisation with each shoe condition immediately prior to testing. For the shod conditions, markers were placed on the outside of the shoes in the corresponding positions to the bony landmarks.

Dancers were instructed to perform eight sautés, bilateral vertical jumps, with the feet on two separate force plates (Model 9287BA, Kistler, Switzerland). Dancers performed sautés in time with RAD syllabus Grade 1 music. Consecutive jumps were performed in second position (feet slightly wider than shoulder-width), with maximal external rotation of the hips, and weight evenly distributed between the feet. The principal investigator observed the force vectors during the trials to ascertain even weight distribution. A trial was deemed unsuccessful if the heels did not stay on the floor in the *demi-plié* during stance phase.[23] Erect posture was maintained throughout the task and dancers were instructed to keep their hands on their waist as they were not