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Do dance floor force reduction and static stiffness represent dynamic floor stiffness during dance landings?

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Abstract

Dance training on floors that are not 'sprung' are assumed to have direct implications for injury. Standards for dance floor manufacture in Europe and North America quantify floor force reduction by measuring the impact forces of drop masses. In addition, many studies of human mechanical adaptations to varied surfaces, have quantified test surfaces using measures of static stiffness. It is unclear whether these methods for the measurement of floor mechanical properties actually reflect dancer requirements or floor behaviour under dancer loading. The aim of this study was to compare the force reduction, static stiffness and dynamic stiffness of a range of dance floors. Dynamic stiffness was measured during dancers performing drop landings. Force reduction highly correlated (p= 0.086) with floors of moderate dynamic stiffness, but was less accurate for high and low stiffness floors. Static stiffness underestimated the dynamic stiffness of the floors. Measurement of floor force reduction using European sports surface standards may provide an accurate representation of dynamic floor stiffness when under load from dancers performing drop landings. The discrepancy between static and dynamic stiffness may be explained by the inertial characteristics of the floor and the rapid loading of the floors during dancer landings. The development of portable systems for measuring floor behaviour under human loads using modern motion capture technologies may be beneficial for improving the quantification of dance floor mechanical properties.

Selection and peer-review under responsibility of the Centre for Sports Engineering Research, Sheffield Hallam University

Keywords: dance; dance floors; force reduction; static stiffness; dynamic stiffness

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1. Introduction

Elite dancers spend large volumes of time rehearsing and performing on dance floors (Allen, Nevill, Brooks, Koutedakis, & Wyon, 2013; Hopper et al., 2014; Nilsson, Leanderson, Wykman, & Strender, 2001). A common assumption within the dance industry is that dance training on floors with insufficient levels of force reduction has implications for injury (Liederbach & Richardson, 2007; Seals, 1987). Dance floors must adhere to floor force reduction standards in which floors are quantified using a simple drop mass system (British Standards Institution, 2006b). Dancer perceptions of floor force reduction have been reported to correlate with force reduction levels (Hopper, Alderson, Elliott, Ackland, & Fleming, 2011), however it is unknown if force reduction is a valid representation of the dynamic behaviour of dance floors under load.

Drop mass systems incorporate a spring as a representation of the leg stiffness demonstrated by humans during locomotion (British Standards Institution, 2006a). However the spring stiffness used in these drop mass systems is far greater than the leg stiffness reported during human locomotion (Ferris, Liang, & Farley, 1999). Furthermore, it is well established that humans inversely adapt leg stiffness to changes in surface stiffness (Ferris et al., 1999). Therefore using a drop mass of constant spring stiffness does not replicate human leg stiffness adaptations to varied floors. Therefore the validity of the drop mass systems for replicating human locomotion may be limited.

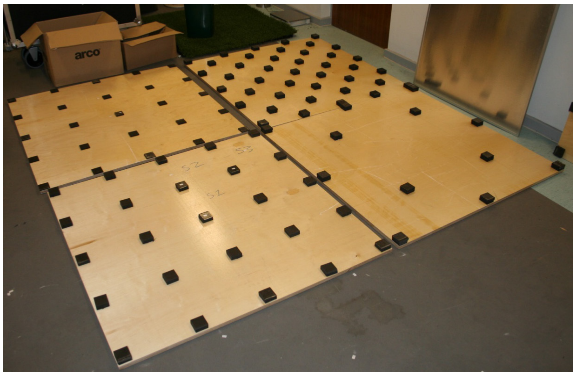
The inverse relationship between human leg stiffness and floor stiffness interactions has been well established in athletes and recently verified in dancers (Hackney et al., 2011; Stiles, James, Dixon, & Guisasola, 2009). The floors used in developing this evidence base were predominantly custom made with springs of constant stiffness under both static and dynamic load (Ferris & Farley, 1997; Ferris et al., 1999). Floor stiffness was quantified in these studies by comparing floor deformation to either; incremental increases in static loads or dynamic vertical ground reaction forces. Commercially manufactured dance floors may not necessarily demonstrate the consistent floor stiffness as reported in the literature. Floors of inconsistent stiffness may be associated with different biomechanical adaptations by dancers to that observed on floors with consistent stiffness. The external validity of the current knowledge of human biomechanical adaptations on varied floors may be limited for dancers, should dance floors demonstrate inconsistent dynamic stiffness.

The aim of this study was to compare the force reduction, static stiffness and dynamic stiffness of a range of dance floors. Force reduction and static stiffness were determined using mechanical tests whereas a floor dynamic stiffness was measured during dancers performing drop landings.

2. Methods

Five custom dance floors were created from 1.2 m x 1.2 m pieces of 18 ply lacquered birch with varied configurations of high and low density neoprene foam squares attached to the underside of the boards (Figure 1). Materials used to construct the floors were provided by Harlequin Sprung Dance Floors Pty Ltd. Floor 1 was used as a reference floor and therefore did not have any neoprene pads.

Force reduction was quantified using the Advanced Artificial Athlete apparatus (Metaalmaatwerk, NL). Force reduction protocols involve dropping a 20 kg mass attached to a 2200 kN/m spring from 0.05 m onto a test floor as described by European standard BSEN 14808 (British Standards Institution, 2006a). Force reduction is calculated as the percentage of the peak force recorded on the test floor compared to that on a concrete floor. A test floor that records peak forces equal to that recorded on concrete has 0% force reduction.



Floor	Pad configuration
1	single wooden panel no pads
2	5x5 single high density pads
3	41 double stacked low density pads
4	5x5 stack of one high density and one low density pad
5	12 double stacked low density pads

Fig. 1: Test floors and pad configurations

Static floor stiffness was quantified by sequentially placing seven, 20 kg weight plates on the centre of the test floors. A retro-reflective marker was placed on a reference point that remained at a constant distance to the central surface of the floors at each load. Twelve Vicon MX (Oxford Metrics, Oxford, UK) cameras and a 1.2 m x 1.2 m AMTI forceplate were used to record the vertical position of the retro-reflective marker and the vertical ground reaction forces at each static load. The static stiffness of the floors at each load was calculated as the change in vertical ground reaction force divided by the change in marker position from the initial unloaded condition.

Dynamic floor stiffness was assessed during drop landings performed by 13 dancers from the West Australian Academy of Performing Arts (Perth, AUS) and one ex-professional dancer (males n=5; females n=8; age 20.7 years ±5.1; mass 60.9 kg ±9.9; height 1.7 m ±0.1). Dancers provided informed consent to participate in the study. The landing protocol required the dancers to hang from a ring with the great toe 0.2 m above the test surfaces. Dancers were instructed to release the ring and perform a single leg landing on the floors. The vertical deformation of the floors during the landing trials was calculated as the mean vertical position of three retro-reflective markers placed on the floor surfaces. Marker positions and ground reaction force data were collected at 250 Hz with the same cameras and forceplate as described in the static stiffness protocols. Data were filtered with a 10 Hz low pass second order Butterworth filter in Vicon Nexus software (Oxford Metrics, Oxford, UK). Dynamic stiffness was calculated at each data point within the dynamic trials using the same method as the static stiffness.

Floor force reduction and mean dynamic stiffness data were compared using bivariate correlations. Frames were identified in the dynamic trials where vertical ground reaction forces were equivalent to that during the weighted static trials. The instantaneous stiffness at the identified frames during the dynamic trials were compared to the static stiffness at the equivalent force levels for each floor using independent t tests (SPSS v22, IBM).

3. Results

Force reduction and mean dynamic stiffness values were highly correlated ($r = -0.824$; $p = 0.086$). However, due to the small number of cases used in the comparisons, the correlations were not significant ($p>0.05$). Large discrepancies between the force reduction and dynamic stiffness of floors 1 and 5 were observed. With floor 1 and

5 removed, the observed r level increased to -0.995 (p=0.062) (Figure 2). Peak vertical ground reaction forces during dynamic trials were consistent, with an average of 1536 N ± 18 and occurred on average 0.104 s ±0.003 after first contact with the floors. The static stiffness of all floors' were significantly ($p<0.001$) lower than the dynamic stiffness levels (Figure 2). Floor static stiffness was relatively constant across the range of loads. Dynamic stiffness of the floors decreased in conjunction with increases in floor force reduction (Figure 2).

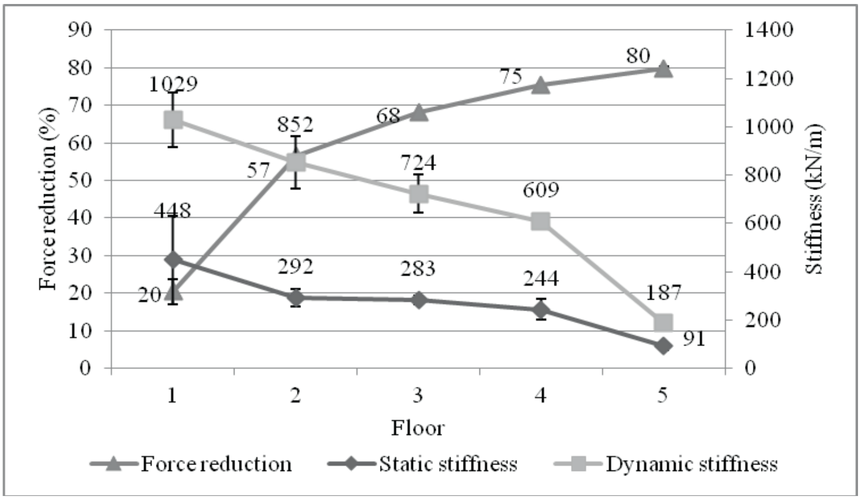


Fig. 2: Mean force reduction, static and dynamic stiffness values for floors 1 -5

4. Discussion

Force reduction provided a close representation of dance floor dynamic stiffness during dancers performing drop landings. A high but insignificant correlation between the floor force reduction and dynamic stiffness was observed. The protocols required for the measurement of force reduction provide a reliable and mobile method of testing dance floors. Given the reported relationship between force reduction, dancer perceptions (Hopper et al., 2011) and dynamic floor stiffness it appears that force reduction is an appropriate method for quantifying dance floor mechanical properties. However, comparison of the dynamic stiffness and force reduction of a greater sample of floors is needed.

Force reduction may be a limited representation of dynamic floor behaviour at very low or high stiffness levels. The greatest discrepancies between floor force reduction and dynamic stiffness were associated with floors 1 and 5. The relative change between the force reduction of floor 1 and floor 2 was much greater than the relative change in dynamic stiffness. Whereas, the relative change in the dynamic stiffness between floors 4 and 5 were much greater than the associated changes in force reduction (Figure 2). This would suggest that the force reduction measurement is more sensitive at low levels of force reduction than actually occurs within floor dynamic stiffness. Whereas, force reduction appears less sensitive to changes in low stiffness floors. In agreement with the observations of this study, Hopper et al. (2011) reported dancer perceptions of high force reduction floors to be more sensitive than the actual force reduction protocols. Therefore caution should be exhibited in interpreting force reduction at these extreme levels when attempting to use force reduction as a representation of floor behaviour under dynamic load.

Static stiffness did not provide an accurate representation of floor dynamic stiffness. Floor dynamic stiffness was significantly greater than static stiffness levels. The inertia of the wooden boards used to construct dance

floors are likely to provide the necessary resistance to load which explains the increased dynamic stiffness of the floors when compared to the static stiffness. Peak vertical ground reaction forces occurred approximately 0.1 s from contact with the floors during the dynamic trials. This epoch was likely insufficient to produce enough momentum in wooden floor boards to allow for the equivalent floor deformation to occur in the dynamic trials as compared to the static trials. In addition, as floor dynamic stiffness increased with increasing load, this would suggest that the response of dance floors to dynamic load is more complex than under static load. Therefore quantifying dance floors using static stiffness protocols does not appear to provide an accurate representation of dynamic floor behaviour and therefore should be used with caution in future studies investigating dance floors. These findings may have further applications for wooden sports floors.

Both force reduction and static stiffness have been used to provide a representation of the dynamic behaviour of floors under human loading. These floor quantification protocols are advantageous as they provide a reliable and portable means of measuring floor properties. The disadvantage of these methods is that they have varying levels of ability to represent floor behaviour under dynamic load. However, the development of accurate measures of dynamic floor behaviour under human load may now be possible should the increasingly sophisticated and portable motion analysis systems be able to overcome the issues of time constraints and repeatability associated with human testing. Directly measuring floor behaviour under human load would clearly provide the best information of floor behaviour in the interests of gaining knowledge regarding the needs of dancers for dance floor mechanical properties, enhance the safety of dance training and prevent dance injuries.

5. Conclusions

Measurements of floor force reduction as referenced by European sports surface standards appear to provide an accurate representation of dynamic floor stiffness when under load from dancers performing drop landings. However, the accuracy appears to be reduced at extremely low or high levels of force reduction. Quantifying dance floors using measurements of static stiffness does not appear to accurately represent dynamic floor stiffness. This inaccuracy may be the result of the rapid loading of the floors during dancer landings and responses of the floors being reliant on the floor inertial characteristics. The development of portable systems for measuring floor behaviour under human loads using modern motion capture technologies may be beneficial in the interests of improving quantification protocols for dance floor mechanical properties which can serve to improve the safety of dance studios and prevent dance injuries.

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