BALLET DANCER INJURIES DURING PERFORMANCE AND REHEARSAL ON VARIED DANCE SURFACES

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Three dance surfaces regularly used by a professional touring ballet company (n=60) were quantified using standard sports surface testing apparatus. Surface sub-structure construction varied between surfaces and a range of surface force reduction values were reported. Injuries and associated variables occurring within the ballet company were recorded by the company medical staff. An injury was recorded if a dancer experienced an incident that restricted the dancer from performing all activities that were required of them for the period 24hrs after the incident. Injuries were delimited to those occurring in the lower limbs or trunk during reported non-lifting dance activity. Analysis of statistical significance was restricted due to a low injury data sample size. However certain trends in the injury data warrant future research. The surface with the highest variability in intra-surface force reduction was associated with the highest injury rates per week, lower limb injuries per week, mean days lost dancing per injury and likelihood of injury per performance day. Variability in intra-surface force reduction may have a stronger association with injury risk than mean surface force reduction magnitudes.

KEY WORDS: dance, injury, sports surface, landing

INTRODUCTION: The mechanical properties of floor surfaces used for athletic performance affect human landing mechanics (Ferris et al., 1999; Moritz et al., 2004) and it seems intuitive that certain floor surface types may have an associated injury risk. Yet epidemiological evidence investigating the relationship between surface properties and athletic injury is limited. Previous comparisons of floor surfaces and athletic injury have not quantified the mechanical properties of the investigated surfaces (Nigg and Segesser, 1988; Ekstrand et al., 2003; Nigg, 2003). Further, the relationship between sports surface and injury is difficult to establish due to confounding variables such as shoe/surface interactions and other environmental conditions (Shorten, 2007). Nonetheless, previous literature has identified that intra-surface variability may pose an injury risk to the athlete (Nigg, 2003) and human landing mechanics differ between known, unexpected or unknown surfaces (Moritz et al., 2004) but are highly adaptable to a known change in surface structure (Ferris et al., 1999).

Ballet dancers are highly trained athletes who demonstrate unique and highly developed motor functions (Imura et al., 2008). Dancers wear footwear during dance activity that provide little impact attenuation and perform in a well rehearsed and controlled environment. Therefore the injuries within a dance population may provide valuable insight into the potential injury risks associated with quantified dance surface mechanical properties.
The majority of dancer injuries are overuse in nature and occur in the lower limbs and trunk (Solomon et al., 1999; Nilsson et al., 2001). The interaction between a dancer and selected floor surfaces has been suggested to influence the incidence of lower limb and trunk injuries. Descriptors such as ‘hard’, ‘stiff’ or ‘unsprung’ have been used to describe floor properties that may present an injury risk to dancers (Bowling, 1989; Khan et al., 1995; Liederbach and Richardson, 2007). The actual mechanical properties of dance floors and how they relate to the incidence of lower limb and trunk injuries need to be quantified to assess any associated injury risks to the dancer. The aim of this study was to compare the lower limb and trunk injury rates within a professional ballet company to the mechanical properties of the surface on which the injuries occurred, as a means of identifying potential surface injury risk criteria.

METHODS: Data Collection: The mechanical properties of three stage surfaces used by a professional ballet company (n=60) were quantified using standard sports surface testing equipment, the advanced artificial athlete (Metaalmaatwork, NL). Advanced artificial athlete test protocols involve a drop mass consisting of a uni-axial accelerometer, a 20kg mass and a 2220N/mm spring with a circular (100mm diameter) impact surface, which is dropped from 55mm above the test surface. Residual analysis determined that the data be filtered at 92Hz with a low pass second order Butterworth filter. Acceleration data, captured at 9600Hz, were then converted to a force time series. The force reduction (FR) of each test point was calculated as the difference in the peak force recorded on the individual test points (F_t) to that on a rigid concrete surface (F_c) as a percentage of the peak force measured on a rigid concrete surface (FR=((F_c-F_t)/F_c)100). The test protocols followed were adopted as per the European standard; Surfaces for sports areas: Indoor surfaces for multi-sports use (BS EN 14808). Testing sessions were conducted in an ambient temperature of 18-21^{o}C.

Test floors consisted of 20-30mm thick plywood boards covered by Harlequin Cascade Vinyl (Harlequin Pty Ltd., London, UK), a thin vinyl layer used to enhance the friction characteristics of the surface. Primary support structures for all surfaces were steel girders, which supported the surfaces above large storage areas. Wooden, metal and/or foam secondary support structures lay in between the plywood and the primary support structures. The orientation and spacing of support structures differed between surfaces. The primary support contact surface area for surfaces 1, 2 and 3 accounted for approximately 9.8%, 6.3% and 14.7% of the total surface area of each surface respectively. Test points were identified on each surface to ensure that FR values on and between floor supports were quantified. Support locations were only identifiable from below the stage and could not be identified by the performing dancers prior to landing.

FR data were compared to the company injury rates. Injury data were collated by the company medical staff over a two year period. An injury was recorded if a dancer experienced an incident that restricted the dancer from performing all activities that were required of them for the period 24hrs after the incident. Injuries were delimited to that occurring in the lower limb or trunk during non-lifting activities. All test venues were within one day’s road travel from the home venue. When at a venue, all dance activity was conducted on the test surface.

Data Analysis: Descriptive statistics of the FR data were generated for each venue. Descriptive statistics of the injury frequencies were generated by grouping injuries into per week or per performance day categories. Total injuries per week were also separated into lower limb and trunk categories and the severity of the injuries were assessed by calculating the mean days missed dancing, as a result of injury. One week at a venue represented approximately 1620 dancer hours, based on 60 dancers, rehearsing or performing 6 days per week for 4.5 hours per day. Limited injury data sample sizes restricted analysis of statistical significance. FR values were compared with the European standard; Surfaces for sports areas: Indoor surfaces for multi-sports use (BS EN 14808).

RESULTS: Descriptive statistics of the FR values and injury data are presented in Tables 1 and 2 respectively. The lowest injury rates for four of the five injury variables occurred on surface 1, which was characterized by relatively high mean FR values across all support structures (45.90%) and moderate intra-surface variability (Std Dev 7.06; Range 21.93%). Surface 1 primary (46.45%) and on and between secondary support (45.46%) FR means differed by 0.99%. Injury rates on surface 2 were the second highest for all injury variables. Surface 2 was characterised by the lowest FR means and FR variability. A large difference in the mean FR values was recorded between surface 2 primary supports (12.88%) and on and between secondary supports (35.46%) but the primary support contact surface area was low relative to the total stage surface area (6.3%), which resulted in a low frequency of variable test points. Injury rates on surface 3 were the highest for four of the five injury variables. Surface 3 was characterised by the largest on and between secondary support FR variability and the largest distance between secondary supports. Surface 3 primary support mean FR (21.51%) was also markedly lower than the on and between secondary support mean FR (39.31%), but surface 3 was more variable than surface 2 due to a higher relative primary support contact surface area (14.7%). None of the surfaces complied with European standard; Surfaces for sports areas: Indoor surfaces for multi-sports use (BS EN 14808) (55-70% FR).

Table 1 Force reduction values for each surface

Primary Support Values (On supports only)

Surface	Test Points	Mean (%)	Standard Deviation	Range (%)	Maximum (%)	Minimum (%)	Distance Between Supports (m)
1	6	46.45	6.84	20.61	54.86	34.25	3.30
2	7	12.88	2.94	8.40	16.17	7.77	3.25
3	9	21.51	2.66	6.46	25.05	18.58	2.40

Secondary Support Values (On and between supports)

Surface	Test Points	Mean (%)	Standard Deviation	Range (%)	Maximum (%)	Minimum (%)	Distance Between Supports (m)
1	20	45.46	6.96	20.15	54.33	34.18	0.38
2	22	35.46	3.35	12.36	41.80	29.45	0.23
3	27	39.31	9.32	35.59	57.33	21.74	0.60

Table 2 Ballet company injury data on each surface

Surface	Weeks at Venue	Performance Days at Venue	Total Injuries per Week	Lower Limb Injuries per Week	Trunk Injuries per Week	Mean Days Lost Dancing per Injury	Performance Days Resulting in Injury
1	3	13	4.50	2.75	1.75	0.12	38%
2	4	20	5.67	4.00	1.67	0.35	50%
3	5	24	6.80	5.40	1.40	0.97	67%

DISCUSSION: This study assessed the lower limb and trunk injury rates within a professional touring ballet company during activity on three quantified performance venue floor surfaces. Assessed in multiple ways, injury rates were highest on the surface, which was characterised by (a) the largest FR variability on and between secondary supports; (b) the largest distance between secondary supports; (c) the primary support mean FR was markedly lower than the mean FR recorded on and between the secondary supports and (d) a high relative primary support contact surface area. As a result of these properties, surface 3 had a high frequency of variable FR values that were unidentifiable by the performing dancers prior to landing. Some support has therefore been provided for the findings of Nigg (2003) that surfaces with high intra-surface FR variability used for human physical activity may pose a greater injury risk to the individual than surfaces with low, uniform surface FR.

The adaptations of human landing mechanics to variations in surface FR are dependent on the individual's pre-landing perception of the impact surface and human landing mechanics change if surface FR is known, unknown or unexpected (Moritz et al., 2004, Ferris et al., 1999). Injury risks associated with these landing strategies are unknown, but the dependence of the neuromuscular system on post-impact sensory feedback for mechanical control on unknown surfaces may cause a delay in the necessary mechanical adaptations to the surface and pre-dispose the lower limb to injury.

The findings of this study are limited due to the low sample size. Nonetheless, the minimal footwear used by dancers and the controlled environment of professional dance delimits many of the confounding variables associated with previous sports surface epidemiological research. It should be noted that all surfaces did provide some FR and that dancer performance on a surface with a 0% FR value may be associated with an injury risk that has not been investigated. In response to these findings the ballet company now uses a portable performance floor on surfaces 1, 2 and 3 that complies with the European standards as quantified by the test protocols used in this study and future investigation of the injury rates on this surface will hopefully be conducted.

CONCLUSIONS: Ballet dancers demonstrate comparable skill and ability to that of elite athletes, but can be required to perform on surfaces that are sub-standard for elite performance. Variability in intra-surface FR, as identified in previous research, may present a greater risk of injury than low variability in intra-surface FR or low mean FR across the surface. Further investigation into the mechanics of human landing on surfaces of unknown FR is required to further investigate surface injury risk criteria.

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