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**Abstract**

Specialist dance floors have been promoted to reduce impact forces and reduce lower limb injury for dancers. 18 trained female dancers carried out 70 continuous ballet jumps on 4 different surfaces wearing an XSENS suit. Three specialist dance floors, Floor A (64% force reduction), Floor B (67% force reduction), Floor C (no data) were compared to Floor D (vinyl-covered concrete - control). Dependent variables for each analysed jump (2,3,4, and 67,68,69) were ankle, knee, hip range of movement (ROM); lower and upper leg angular velocities and pelvis vertical acceleration. No main effects were reported for dance floor, first and last jump series. Comparison of the floors against Floor D reported a main effect for the dance floors ($p=0.001$), first and last jump series ($p=0.001$). Between-subject effects noted that ankle ROM was significantly greater for trials on floor A ($p=0.007$) compared to floor D. ROM data significantly decreased between the first and last jump series whilst vertical pelvis accelerations increased except for floor A. Within the current study, a foam backed vinyl floor (C) provided better shock absorption than floors with higher deformation characteristics (A and B) and none of the specialist dance floors performed better than vinyl covered concrete (D).

**Key words**: Dance, Stiffness, Attenuation, Sport Surfaces, Compliant floors

**Introduction**

Injury incidence has been reported to be between 0.18-4.7 injuries per 1000 hours across theatrical dance genres[1]. There is an increased incidence of lower limb injuries [2-4] in these dance genres that has been linked potentially to the interaction between intrinsic and extrinsic aetiological factors[5] such as limb alignment[6], muscular strength[7] and dance floor properties[8]. Moreover, previous research noted that often "other/unknown" were recorded as the main causes of injury because of the prevalence of chronic injuries within this population[5], therefore a single cause is impossible to determine. Self-report injury surveys reported that 20-25% of dancers perceived that dancing on an unsuitable floor was the cause of their injuries[4, 9]. The dance industry has promoted the instillation of specialist sprung dance floors[10] as an extrinsic preventative measure as dancers' footwear, if worn at all, typically do not integrate shock absorbing materials into the shoe's construction[11]. Specialist floors have varying force reduction properties depending on how they are constructed[12, 13]; full sprung and semi-sprung constructed dance floors have force reductions between 64%-67%[14] whilst other foam-backed vinyl constructions have no published data.

Early studies suggested dancers had increased limb stiffness (ratio of vertical ground reaction force to compression of the lower leg) when landing on sprung floors compared to floors with less deformation characteristics[15]. This suggests that the floor acted as a force-absorber and could potentially be an injury preventative intervention. Reeve et al[16] noted no changes in lower body kinematics between different floor stiffnesses, which is in contrast with Hopper et al[17] findings that ankle joint range of motion, peak angular velocity and peak joint moments all significantly increased with an increase in floor stiffness. These studies' methods used drop tests, from stepping off a box, rather than a countermovement jump onto a covered force platform. Afifi and Hinrischs[18] cautioned this approach if the aim is to relate the data with landing from a jump. They reported that the time to peak ground reaction force and joint flexion angles at peak ground reaction force were both greater for the countermovement jump than a drop test. Hackney et al [19] tested the difference in lower limb joint angles and angular velocity during a basic sauté on a low stiffness floor (64% deformation) and a vinyl-covered hardwood on concrete. They noted the low stiffness floor resulted in significant decrease in knee angle and angular negative velocity of the ankle; concluding that a reduced floor stiffness may help decrease the likelihood of lower extremity injuries.

Previous studies have also used limited number of trials within their methodologies (3-6 trials[16, 17] per floor). As the cause of dance injuries is often cited as fatigue the use of such limited number of trials may fail to show how dancers or the floor responds to a more ecological valid environment

where dancers have to carry out multiple jump series over a short period of time (dance class, rehearsal or performance)[20] .

Dancers often have to perform on different floors, whether on tour moving from venue to venue, or within the confines of their training venue. Hopper et al[21] tested the floors of a number of theatre venues that a professional ballet company visited using an Advanced Artificial Athlete (Deltec Equipment, Netherlands) and compared the company's injury incidence. They noted that it was often the amount of variability in the dance floor deformation, rather than the mean floor deformation characteristics, that lead to increased injury incidence. Anatomically, the sensory feedback from the foot's plantar glabrous epithelium layer is thought to react to the floor's hardness and alter leg stiffness correspondingly[22]. This adaptation to a new surface stiffness occurs very rapidly often within a single contact[23], though when floor stiffness variability is masked due to varying substructure construction it can lead to increased injury incidence[21].

There have been some limitations in the previously mentioned research particularly regarding ecological validity; whether it is the total number of jumps in the trials or the manner in which the jumps were performed. Therefore, the current study intends to improve this validity by carrying out multiple jump series on different dance floors and monitor how the dancers adapt to the different floor deformation characteristics; this is similar to a protocol developed by Ferris and Farley[24]. Via an initial pilot study, using 12 trained dancers (current and ex-professional dancers) independent of the main study's participants, we measured the number of continuous jumps they could manage with three termination criteria; voluntary cessation, jump height was 50% less than their highest of their first 5 jumps, or their technique visibility deteriorated. The total number of completed jumps ranged between 57-91, with the median score being 68. The aim of the current study was to investigate the kinematic responses to landing on 4 dance floors of different deformation qualities by examining the first and last 5 jumps of a continuous 70-jump series.

**Materials and Methods**

We employed a double-blind cross over design where the participants and statistician were blinded to the deformation characteristics of the different dance floors. Ethical approval was granted by the University of Wolverhampton (03/19/RH/UOW) and complied with Harriss et al [25]. Three individual dance floors (3m x 3m) were specifically built for this study by their manufacturer onto a concrete subsurface. The company were not involved in the data collection, its analysis or interpretation and they did not have the right to approve/disapprove publication. We coded the

floors as A, B, and C. Floor A was a “basket weave” design comprised of three layers of pine planks sandwiching dual-density elastomer blocks covered by a plywood sheet and a vinyl surface resulting in a force reduction of 64%[14, 19]. Floor B was a modular vinyl covered plywood panel supported by dual-density elastomer pads with force reduction of 67%[14]. Floor C was a vinyl floor backed with PVC support and closed-cell foam backing providing cushioning, there are no published force reduction data for this floor. All the floors were covered by the same vinyl surface to give a uniformed appearance and feel. The fourth floor (D) was the same vinyl surface only, laid over the concrete substructure and acted as a control. Participants were told it was a new type of touring dance floor.

Eighteen female dancers (age 22 ±3.74, height 162.2cm ±6.29, mass 60.2kg ±13.64) with a minimum of 6 years dance training and currently doing a minimum of 18 hours+ dance training per week in ballet and/or contemporary dance volunteered for the study. Participants who were injury free at the time of testing and did not require modification their dance training in the last 8 weeks due to injury, were given an information sheet detailing the research design and their rights before signing an informed consent. Standing height was measured to the nearest 0.1 cm using a Seca stadiometer (Seca GmbH, Hamburg, Germany), with the participants in bare feet and their heads positioned in the Frankfort horizontal plane. Total body mass was measured to the nearest 0.1 kg with a Seca beam balance 710 (Seca GmbH, Hamburg, Germany). Each participant wore an XSENS suit (XSENS, Netherlands); which comprises of a series of 3D gyroscopes, 3D accelerometers and 3D magnetometers that collects data at 800Hz. The XSENS system has been shown to be a clinically valid and reliable method of collecting kinematic data[26] within a field setting, allowing participants to move between the floor conditions without the need for software recalibration.

After putting on the appropriately sized XSENS suit, and headband, the suit was paired with the computer via Bluetooth that allowed real-time data capture. Each participant’s anatomical measurements (SI) were taken and recorded into the XSENS software (height, foot length, ankle height, knee height, hip height, hip width, arm span, shoulder width, shoulder height). Subsequently, participants were asked to stand still for 30 seconds in the N-pose (feet one foot width apart, arms to the side with thumbs forward, head in the Frankfort plane) for calibration purposes.
After a 10-minute self-guided warm-up, that included dynamic stretching, light jogging and small jumps, participants were asked to complete 70 continuous ballet jumps (*sautés* in first position) at a tempo of 98 beats per minute on each floor with a 30-minute rest between floors. Participants were asked to jump in time and keep up with the metronome, land correctly (initial contact with the toes then working through the rest of the foot to the heel and completing a plié), keep their arms akimbo

and point their feet when in the air. Verbal encouragement and reminders were given to the dancers throughout the trials. The 30-minute rest period between floor trails would allow a complete muscular recovery between the trials therefore removing a potential fatigue carry-over effect. The order in which participant tested the floors was randomised using an online programme (www.randomizer.org). Jump height and foot-floor contact time were measured using the Optojump system (Microgate, Bolzano, Italy).

Only the first 5 jumps (first series) and the last 5 jumps (last series) of the total jumps were recorded for further analysis. Kinematic data, jump height and foot-floor contact time of the landing phase of the middle 3 jumps (2, 3, 4) for the first and last 5-jump series were analysed. The start of the landing phase was considered to be the initial spike for the right toe in the Z-axis above 25m.s$^{-1}$. The data from the XSENS suit were analysed via XSENS's MVN Analyze software using a Kalman filter to smooth the data and down-filtered to 60Hz[26]. Dependent variables for each analysed jump were maximal range of movement (ROM) for ankle dorsiflexion, knee flexion, hip flexion, total ROM for ankle, knee and hip; angular velocities of the lower and upper leg, and the vertical acceleration of the pelvis. Data for just the right leg were analysed.

To reduce the potential confounding effect of variations between the participants, the difference in each dependent variable from floors A, B and C were analysed in comparison with floor D (the control floor) for each jump for each participant, concordant with Hackney et al's methods[19] . For example, the difference in ankle ROM for jump 3 for participant 2 was calculated between floors D and A, D and B and D and C. The control floor's data was coded "0" and the data for the other floors were the variation above and below these data points. This was then repeated for each participant, for each jump (i.e., 2,3,4 and 67, 68,69), and for each independent variable (vertical jump height, contact time, ankle dorsiflexion, knee flexion, hip flexion, lower leg angular velocity, upper leg angular velocity and pelvis vertical acceleration).

The kinematic data were further normalised to account for the participant's different jump heights; each trial's range of movement, angular velocity and acceleration were divided by the respective jump height thereby normalising participants' data. The vertical acceleration data were also normalised against total ROM to estimate the effect of the body's force absorbing capabilities against vertical acceleration.

In a novel method to account for individual variations in jump height and intrinsic force absorption (total lower leg ROM or plié), the vertical acceleration data for the pelvis for each jump was divided by jump height and then by total lower leg ROM for that jump. The result of the equation was then multiplied by the participants' mean vertical jump height and total lower leg ROM. The rationale here was that differences in the vertical acceleration provide an indication of the force absorbing capacities of the different floors for a standardised jump height and plié. All data sets are available at https://doi.org/10.6084/m9.figshare.17143037

Statistical analysis was carried out by a blinded statistician. Levene's tests of equality of error of variance were initially performed to establish normal distribution of all variables' data. Combined participant descriptive data, mean ± standard deviation, were calculated for all the dependent variables for the first series (jumps 2, 3, 4) and second series (jumps 67, 68, 69) for all the datasets (raw, comparative and normalised data) . Three factorial design (2x4x7) with contrast and Bonferroni post-hoc analyses were carried out. Effect size was calculated using partial eta squared ($\eta^2$), with a small effect being 0.01, moderate effect 0.06 and a large effect 0.14. Statistical significance was set at $p \leq 0.05$

**Results**

Tables 1 and 2 provide descriptive data for all the dependent variables in comparison to the control floor (Table 1), and normalised for jump height (Table 2); the basic descriptive data for each floor are available as a Supplemental Table A. All dependent variable data were normally distributed, therefore Pillai's Trace statistic was used throughout the analyses.

No main effects were reported for dance floor, first and last jump series, or dance floor* first and last jump series for the basic data (Supplemental Table A). Between subject effect analysis also indicated no significant differences in the dependent variables between the dance floors or between dance floor* first and last jump series ($p > 0.05$). Significant differences were noted for two variables between first and last jump series; jump height significantly increased between the first and last jump series ($F_{1,253}=6.454$; $p=0.012$) but with a small effect size (partial $\eta^2 = 0.026$) and a mean jump height difference of less that 1.5 cm. Likewise, vertical pelvis acceleration on landing significantly increase ($F_{1,253}=9.873$; $p=0.002$) with a small to moderate effect size ($\eta^2 = 0.038$). Post-hoc analyses reported no significant differences for any of the dependent variables between the 4 dance floors.

Table 1: Mean (±standard deviation) data for all participant's dependent variables reported as difference in comparison with control floor data for first series (jumps 2, 3, 4) and second series (jumps 67, 68, 69)

| | | Jumps | Control D Actual data | Vinyl C | Liberty B | Woodspring A |
|---|---|---|---|---|---|---|
| | | | | Difference in comparison with floor D | | |
| Jump | Vertical jump height (cm) | First series | 15.1 ±4.61 | 0.28 ±3.29 | -0.26 ±2.98 | -0.59 ±2.57 |
| | | Second series | 16.7 ±4.11 | 0.19 ±1.81 | -0.41 ±1.84 | -0.46 ±1.98 |
| | Contact time (secs) | First series | 0.339 ±0.08 | 0.00 ±0.03 | 0.00 ±0.04 | 0.01 ±0.03 |
| | | Second Series | 0.323 ±0.07 | 0.00 ±0.2 | 0.00 ±0.02 | 0.00 ±0.01 |
| Joint range of movement | Ankle dorsiflexion ($^0$) | First series | 36.1 ±5.72 | 3.04 ±9.19 | 0.95 ±3.81 | 3.38 ±9.23 |
| | | Second series | 36.8 ±6.31 | 1.02 ±4.14 | 0.36 ±3.71 | 1.68 ±3.42 |
| | Knee flexion ($^0$) | First series | 67.8 ±11.07 | 6.06 ±18.75 | -0.17 ±5.58 | 2.64 ±13.53 |
| | | Second series | 67.9 ±9.45 | -0.40 ±4.97 | -0.04 ±5.41 | 0.61 ±4.17 |
| | Hip Flexion ($^0$) | First series | 27.1 ±7.92 | 1.82 ±9.54 | 1.00 ±4.79 | 1.01 ±5.68 |
| | | Second series | 26.1 ±9.93 | -3.15 ±8.66 | -2.45 ±5.11 | 0.62 ±4.64 |
| | Total lower limb ($^0$) | First series | 130.9 ±22.52 | 10.94 ±35.61 | 1.78 ±10.64 | 7.04 ±26.67 |
| | | Second series | 130.8 ±21.37 | -2.53 ±12.95 | -1.14 ±10.12 | 2.91 ±7.90 |
| Angular velocity | Lower leg ($^0$.sec$^{-1}$) | First series | 5.86 ±2.74 | 0.50 ±7.46 | -1.05 ±5.85 | 0.34 ±3.09 |
| | | Second series | 6.11 ±2.27 | -0.03 ±2.66 | 0.18 ±2.75 | -0.38 ±7.52 |
| | Upper leg ($^0$.sec$^{-1}$) | First series | 3.87 ±2.62 | -0.2 ±3.50 | -0.9 ±3.28 | 0.52 ±2.93 |
| | | Second series | 2.58 ±1.75 | 0.03 ±2.43 | -1.15 ±5.89 | 0.18 ±2.34 |
| Vertical acceleration | Pelvis (m.sec$^{-2}$) | First series | 42.36 ±12.16 | -5.48 ±19.05 | -3.49 ±14.56 | 1.02 ±13.79 |
| | | Second series | 50.16 ±14.77 | 2.43 ±17.69 | 2.09 ±13.15 | -2.41 ±15.44 |

Analysis of the individual participant's dependent variables against the floor D (control) (Table 1) noted significant main effects for the dance floors ($F_{1110}$=2.034; p=0.001, $\eta^2$ = 0.047), first and last jump series ($F_{368}$=3.114; p=0.001, $\eta^2$ = 0.071) and dance floor* first and last jump series ($F_{1110}$=1.580; p=0.03, $\eta^2$ = 0.037); these all yielding a small to moderate effect size. Between-subject effects reported a significant difference in ankle ROM ($F_{3,376}$=4.168; p=0.006, $\eta^2$ = 0.032) and Bonferroni results indicating ankle ROM was significantly greater for trials on floor A (p=0.007) compared to floor D. Significant differences in first and last jump series data were also noted for knee ROM ($F_{1,376}$=227.61; p=0.037, $\eta^2$ = 0.022), hip ROM ($F_{1,376}$=139.03; p=0.007, $\eta^2$ = 0.032), total lower limb ROM ($F_{1,376}$=812.99; p=0.047, $\eta^2$ = 0.021) and vertical pelvis acceleration ($F_{1,376}$=641.23; p=0.017, $\eta^2$ = 0.027). All the ROM data significantly decreased between the first and last jump series whilst vertical pelvis accelerations increased. Knee ROM data from floors A and C reported a greater decrease than floor B, whilst hip ROM noted the greatest decrease from trials on floors B and C. Vertical pelvis acceleration increased on floors B and C whilst floor A data reported a decrease. In all instances the effect size was small and the differences compared to the control floor (D) whilst statistically different were biologically irrelevant (Table 1).

Table 2 Mean (±standard deviation) data for all participant's dependent variables normalised for jump height and reported "per cm jump height" for first series (jumps 2, 3, 4) and second series (jumps 67, 68, 69)

| | | Jumps | Control D | Vinyl C | Liberty B | Woodspring A |
|---|---|---|---|---|---|---|
| Joint range of movement | Ankle dorsiflexion ($^0$) | First series | 2.39 ±0.64 | 2.29 ±0.49 | 2.34 ±0.91 | 2.20 ±0.62 |
| | | Second series | 2.24 ±0.48 | 2.17 ±0.51 | 2.12 ±0.58 | 2.08 ±0.53 |
| | Knee flexion ($^0$) | First series | 4.49 ±1.47 | 4.24 ±1.15 | 4.52 ±2.02 | 4.36 ±1.26 |
| | | Second series | 4.10 ±1.01 | 4.11 ±1.01 | 4.02 ±1.05 | 3.92 ±0.93 |
| | Hip Flexion ($^0$) | First series | 1.83 ±0.79 | 1.75 ±0.71 | 1.78 ±1.02 | 1.78 ±0.76 |
| | | Second series | 1.57 ±0.68 | 1.75 ±0.78 | 1.68 ±0.72 | 1.49 ±0.69 |
| | Total lower limb ($^0$) | First series | 8.82 ±2.79 | 8.27 ±2.18 | 8.63 ±3.86 | 8.34 ±2.48 |
| | | Second series | 7.91 ±1.91 | 8.04 ±1.94 | 7.82 ±2.13 | 7.49 ±1.89 |
| Angular velocity | Lower leg ($^0.sec^{-1}$) | First series | 0.403 ±0.23 | 0.495 ±0.81 | 0.455 ±0.39 | 0.376 ±0.18 |
| | | Second series | 0.380 ±0.16 | 0.377 ±0.17 | 0.390 ±0.15 | 0.381 ±0.39 |
| | Upper leg ($^0.sec^{-1}$) | First series | 0.267 ±0.21 | 0.300 ±0.17 | 0.267 ±0.18 | 0.231 ±0.13 |
| | | Second series | 0.23 ±0.13 | 0.212 ±0.11 | 0.311 ±0.35 | 0.201 ±0.12 |
| Vertical acceleration | Pelvis ($m.sec^{-2}$) | First series | 2.87 ±0.23 | 3.37 ±1.45 | 3.01 ±1.26 | 2.84 ±1.42 |
| | | Second series | 3.11 ±1.19 | 2.97 ±1.17 | 2.88 ±0.92 | 3.12 ±0.99 |

The dependent variables relative to jump height indicated no main effect for dance floor, first and last jump series, or interactions between dance floor* first and last jump series (Table 2). Only lower leg ROM reported a between-subject effect with all reporting a significant decrease in ROM between first and last jump series; ankle ($F_{1,366}$=4.928; p=0.027, $\eta^2$ = 0.013), knee ($F_{1,366}$=6.595; p=0.011, $\eta^2$ = 0.018), hip ($F_{1,366}$=3.749; p=0.050, $\eta^2$ = 0.010), and total lower leg ROM ($F_{1,366}$=6.157; p=0.014, $\eta^2$ = 0.017). Contrast analysis noted that ankle ROM was significantly lower for floor A than D. In all instances the effect size was small and whilst statistically different were biologically irrelevant (Table 2).

Table 2 Mean (±standard deviation) data for all participant's dependent variables normalised for jump height and reported "per cm jump height" for first series (jumps 2, 3, 4) and second series (jumps 67, 68, 69)

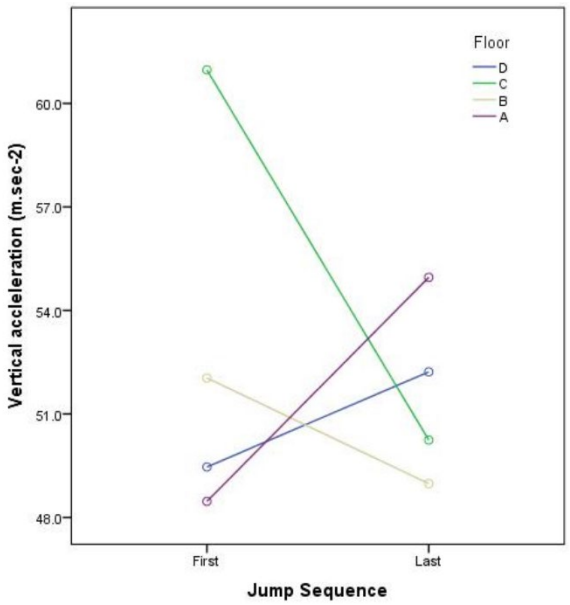


Figure 1: Possible trend in normalised vertical pelvic vertical acceleration data between the different dance floors

**Discussion**

The aim of the current study was to investigate the kinematic responses to landing on 4 dance floors of different deformation qualities by examining the first and last 5 jumps of a continuous 70-jump series. Initial analysis of the data showed that there was a slight increase in jump height as only the heights of the two 5-jump series were measured, it could be that participants paced themselves rather than attempt maximal exertion of each jump repetition. This replicates the lived experience of jumps within a dance class setting, where the focus is rarely on jump height but dance aesthetics[27].

The monitoring of the vertical acceleration at the pelvis provide data on how the shock of landing is dissipated through extrinsic (dance floor) and intrinsic (lower limb joint ROM) methods. We noted a slight increase in vertical pelvic acceleration over the jump series for the dance floors A, B and D, with only Floor C reporting a modest decrease. These mimics the noted increases in jump height for the second series and generally the higher the jump, the greater the landing acceleration, unless it is dissipated by either intrinsic or external shock absorption. When the vertical acceleration was standardised in relation to individual jump height (Table 2) floors D (control) and A (64% force reduction) initially had the lowest accelerations per centimetre vertical jump, but both increased slightly by the second jump series. Floors C and B noted a decrease in vertical acceleration over time with floor C reporting the largest, though moderate, beneficial change of all the floors. The decrease

in pelvic vertical acceleration can't be accounted for by a decrease in jump height as jump height increased. Therefore, the floor construction potentially provided a degree of force absorption that reduced vertical acceleration. The benefits of attenuating vertical acceleration through the dance floors' construction does not seem to materialise for floors A and B despite claiming to have 64% and 67% force reduction characteristics.

Ferris and Farley[24] reported an inverse relationship between leg and surface stiffness, with the leg stiffness (the distance between pelvis and floor) greatly increasing on surfaces with lower stiffness or increased deformation characteristics. They concluded that humans adjusted their leg stiffness to accommodate different surface stiffness. This adjustment in leg stiffness allows contact time to remain nearly constant irrespective of the surface; the near constancy of contact time across the different surfaces was a trend corroborated in the current study (Supplemental Table A).

Unlike Ferris and Farley results[24] we noted little change in leg kinematics across the different dance floors (Table 2). Taking Ferris and Farley's premise it could be assumed that floor D would result in the greatest total lower limb range of movement (ankle, knee and hip) to compensate for the lack of floor deformation. However, Hackney et al[19] reported that a floor with high stiffness characteristics caused an increase in knee flexion during ballet jumps (*sautés*) compared to a purpose built dance floor with a deformation of 64%. Although they reported a statistical difference, the mean difference between the hard and soft surfaces was just $2.4^0$ knee flexion. In contrast, our results indicated the opposite with the specialist dance floor either having the same (Floor B) or greater (Floors A and C) knee flexion than the data from the control floor (Table 1). Participants in fact had very similar total lower limb ROM between the floor with the greatest deformation (floor B – 67% force reduction) and the control floor. Floor C reported the biggest overall change in lower limb ROM between first and last jump series compared to the control floor; with initially lower ankle and knee ROM that increased to similar values as the control floor by the last jump series; this could account for the noted decrease in pelvic accelerations over the same time period.

Standardisation with jump height (degrees ROM per cm vertical jump height) reported no difference between floors for the ankle, knee and hip ROM for either the first or last jump series. Results from Floors D and A revealed the largest decrease in ROM change between the two jump series, approximately 1°per cm vertical jump, with floor C the lowest at 0.23° per cm. The vertical pelvic accelerations were normalised for intrinsic shock absorption (total lower leg ROM) and jump height before multiplied by the groups' mean vertical jump height and total lower leg ROM. The assumption being that the floors with the greatest deformation characteristics would have the lowest vertical accelerations at the pelvis compared to the stiffer floors, in particular floor D, the

control. Although no significant effects were reported, figure 1 highlights a possible trend between the floors. Pelvic vertical acceleration decreases over time for floors B and C, this suggests that for the same jump height and intrinsic shock absorption, floors B and C absorb more vertical acceleration through their deformation characteristics. Floor B has force reduction characteristics of 67%[14], whilst for Floor C there are no published force reduction data but it is a vinyl floor backed with PVC support and closed-cell foam backing providing cushioning. Floor A and D reported an increase in pelvic vertical acceleration despite floor A reporting force reduction characteristics of 64%[14, 19]; Floor D was the same vinyl surface over the concrete substructure and therefore acted as a control. These data highlight the observation that human-floor interaction can differ from mechanical testing and raise similar issues as reported within sport shoe construction[28].

Abergel et al[29] findings suggested that when fatigued, dancers may adopt a softer landing strategy, or increased lower limb ROM. For floors C and B, total ROM did increase slightly in the current study (~3°), whilst the dancer's ROM on the control floor remained the same and decreased on floor A. Our study used a similar protocol as McNeal et al[30], which noted that athletes' knee flexion and ankle dorsiflexion decreased over a 60-second period of continuous jumping along with reduced muscle activation. They also reported that there was an increased use of trunk movement over time that accounted for an altered jumping strategy as fatigue set in. McNeal's study does highlight the difference between "athlete" and "dance" research; in their study participants were asked to perform maximal jumps throughout and the change in jumping strategy employed by their participants is secondary to achieving maximal jump height. In dance, the jumping strategy takes precedence over jump height and dance teachers/coaches would instil the importance of maintaining the strategy to the detriment of jump height. Therefore, the altered strategy reported by McNeal of increasing the use of the trunk to maintain vertical acceleration when muscle fatigue sets in is not an option for a dancer, particularly in ballet where maintaining an upright trunk is an intrinsic element of the ballet aesthetic. Furthermore, many Western style dance genres are executed with music, therefore jumping follows a pre-established tempo, as implemented within this study, which delimits maximum jump height as take-off and landing needs to occur on a rhythmic beat.

This study is limited by a lack of kinetic data to allow comparison with previous studies[15, 31], which would have required a smaller dance floor surface area situated over a force platform (40 x 60 cm). By increasing the dance floor area, we increased the ecological validity of the study as dancers could jump normally without worrying about missing a specific area. The larger floor surface area would also react to impact much closer to that experienced within a dance studio than a smaller segment. Anecdotally, when the dancers knew we were about to collect data their jumping

technique visibly improved (higher jumps, less leg stiffness). Replication studies may wish to disguise the data collection period to avoid this effect.

Future research needs to look at the dancer-footwear-floor interaction. In the current study participants jumped without footwear to maximise the afferent feedback from the soles of their feet which to a large extent determines the resulting leg stiffness. Only a few dance genres actually dance or perform in bare feet and a previous study[32] noted significant differences in dynamic postural stability when landing in shoes with different midsole thicknesses. Therefore, how the body responds to landing when the footwear potentially masks the afferent pressure feedback and increases leg stiffness needs to be examined.

**Conclusion**

In summary the deformation characteristics of dance floors on attenuating human impact forces needs greater examination. The reliance on mechanical testing to determine a floors potential benefits do not consider successfully, the complexity of the human body's response to different surface stiffnesses. Within the current study, a foam backed vinyl floor (C) provided better force absorption than floors with higher deformation characteristics (A and B) and none of the specialist dance floors performed better than vinyl covered concrete (Floor D).

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Supplemental Table A: Descriptive data for jump height, contact time and all dependent kinematic variables

| | | Jumps | Control D | Vinyl C | Liberty B | Woodspring A |
|---|---|---|---|---|---|---|
| Jump | Vertical jump height (cm) | First series † | 15.1 ±4.61 | 15.2 ±4.26 | 15.7 ±5.12 | 15.9 ±5.05 |
| | | Second series † | 16.7 ±4.11 | 16.6 ±3.89 | 16.9 ±4.45 | 17.2 ±3.99 |
| | Contact time (secs) | First series | 0.339 ±0.08 | 0.336 ±0.07 | 0.341 ±0.08 | 0.338 ±0.08 |
| | | Second series | 0.323 ±0.07 | 0.327 ±0.07 | 0.329 ±0.07 | 0.318 ±0.06 |
| Joint range of movement | Ankle dorsiflexion (°) | First series | 36.1 ±5.72 | 35.7 ±5.82 | 35.3 ±5.89 | 34.7 ±6.61 |
| | | Second series | 36.8 ±6.31 | 36.2 ±6.66 | 36.3 ±7.18 | 35.5 ±6.63 |
| | Knee flexion (°) | First series | 67.8 ±11.07 | 67.4 ±11.01 | 68.0 ±10.17 | 68.7 ±9.84 |
| | | Second series | 67.9 ±9.45 | 69.1 ±9.97 | 68.4 ±9.19 | 68.2 ±8.68 |
| | Hip Flexion (°) | First series | 27.1 ±7.92 | 26.9 ±10.47 | 26.3 ±8.22 | 26.96 ±9.09 |
| | | Second series | 26.1 ±9.93 | 27.4 ±8.41 | 28.1 ±9.16 | 24.8 ±9.16 |
| | Total lower limb (°) | First series | 130.9 ±22.52 | 130.2 ±24.64 | 129.6 ±21.05 | 130.3 ±22.63 |
| | | Second series | 130.8 ±21.37 | 132.8 ±22.16 | 132.8 ±22.35 | 128.5 ±22.04 |
| Angular velocity | Lower leg (°.sec$^{-1}$) | First series | 5.86 ±2.74 | 6.78 ±7.48 | 6.92 ±6.23 | 5.89 ±2.36 |
| | | Second series | 6.11 ±2.27 | 6.14 ±2.57 | 6.32 ±2.31 | 6.49 ±7.52 |
| | Upper leg ($^{\circ}$.sec$^{-1}$) | First series | 3.87 ±2.62 | 4.41 ±1.99 | 3.96 ±2.18 | 3.57 ±1.73 |
| | | Second series | 2.58 ±1.75 | 3.55 ±2.11 | 5.04 ±5.64 | 2.39 ±1.97 |
| Vertical acceleration | Pelvis (m.sec$^{-2}$) | First series ‡ | 42.36 ±12.16 | 51.03 ±18.65 | 45.85 ±17.29 | 44.09 ±17.29 |
| | | Second series ‡ | 50.16 ±14.77 | 47.73 ±16.25 | 47.59 ±13.68 | 52.57 ±15.14 |