Mechanics of Jazz Shoes and Their Effect on Pointing in Child Dancers

Alycia Fong Yan, Richard Smith, Benedicte Vanwanseele, and Claire Hiller
Exercise, Health and Performance, Faculty of Health Science, University of Sydney, Lidcombe, NSW, Australia

There has been little scientific investigation of the impact of dance shoes on foot motion or dance injuries. The pointed (plantar-flexed) foot is a fundamental component of both the technical requirements and the traditional aesthetic of ballet and jazz dancing. The aims of this study were to quantify the externally observed angle of plantar flexion in various jazz shoes compared with barefoot and to compare the sagittal plane bending stiffness of the various jazz shoes. Sixteen female recreational child dancers were recruited for 3D motion analysis of active plantar flexion. The jazz shoes tested were a split-sole jazz shoe, full-sole jazz shoe, and jazz sneaker. A shoe dynamometer measured the stiffness of the jazz shoes. The shoes had a significant effect on ankle plantar flexion. All jazz shoes significantly restricted the midfoot plantar flexion angle compared with the barefoot condition. The split-sole jazz shoe demonstrated the least restriction, whereas the full-sole jazz shoe the most midfoot restriction. A small restriction in metatarsophalangeal plantar flexion and a greater restriction at the midfoot joint were demonstrated when wearing stiff jazz shoes. These restrictions will decrease the aesthetic of the pointed foot, may encourage incorrect muscle activation, and have an impact on dance performance.

Keywords: plantar flexion, stiffness, dance, footwear, performance

Scientific research on dance is important from a performance and injury minimization perspective (Washington, 1984), with many areas of investigation still in their infancy. The effect of footwear design on the restriction or enhancement of dance movement is a relatively uncharted area of research. Dancers spend a large proportion of their time on their feet, so healthy, pain-free feet are imperative regardless of a dancer’s age, standard or level of involvement. Therefore, the footwear that dancers use is very important.

A recent systematic review of the literature (Fong Yan, 2011) found that no studies examined the effect of dance footwear on foot motion and only four studies (Colucci & Klein, 2008; Dozzi, et al., 1989; Reid, 1988; Tuckman, et al., 1991) directly assessed the impact of dance footwear on injury risk. Investigations of the effect of dance footwear on motion are relatively few when compared with running shoe research.

Running shoe research has investigated the effect of the hardness of the outsole and overall shoe stiffness on gait. It was found that different materials used in the outsole could alter muscle specific EMG intensity, indicating muscle activation changes in the lower limb (Nigg, et al., 2003; Wakeling, et al., 2002) before heel strike. Atwells and Smith (2000) investigated the effect of stiff shoes and found that the rigidity of the running shoes altered walking technique, increasing rearfoot motion in the sagittal and transverse planes.

As there are various designs of dance footwear available for each dance style (Cheskin, 2000), the impact of footwear stiffness on muscle activation patterns and foot dynamics should be investigated for dance footwear. Dance shoe design incorporates both function, as in pointe shoes assisting a dancer maintaining the pointe position (standing on the tips of the toes) (Goulart, et al., 2008) and aesthetic appeal. For example, there are many varied designs of jazz dance footwear ranging from rigid to flexible, slimline to chunky depending on the style of the dance routine.

The most popular dance style among young children appears to be jazz, perhaps because the children can dance to recent pop songs and the dance style is relatively less disciplined compared with ballet. At this young age, children learn the foundations of technique. Footwear that alters foot movement could have implications for the development of incorrect technique (Denton, 1997; Greer & Panush, 1994; Kadel, 2006; Kravitz, et al., 1984; Macintyre & Joy, 2000; Micheli, 1983; Teitz, et al., 1985) and muscle weakness (Denton, 1997; Greer & Panush, 1994; Taunton, et al., 1988), both of which contribute to injuries (Khan, et al., 1995).
A very important aspect of the aesthetics and technique of theatrical dance styles, in particular ballet and jazz, is that feet are pointed (maximally plantar flexed) during dance movements. Feet should be pointed when both feet are in the air during jumps, when one leg is held in the air or during any weight transference when both feet are in contact with the floor. Teachers and examiners of dance need to see foot movement clearly to ensure correct technique execution. The common belief of teachers is that some footwear designs can make the feet work harder or hide the foot while others can enhance the aesthetic of the plantar flexed foot.

The primary aim of this study was to quantify the externally observed angle of plantar flexion in child dancers wearing various jazz shoes. The hypothesis was that there would be no difference between maximal plantar flexion angles at the ankle, midfoot and metatarsophalangeal joints, achieved in different jazz shoe styles.

The secondary aim was to investigate the mechanical stiffness of the jazz shoes when bent in the sagittal plane. The hypothesis was that there would be no difference in plantar flexion stiffness between jazz shoe styles and that jazz shoes are stiffer than thongs and more flexible than school shoes.

**Methods**

As the main focus of the study was the effect of dance shoes on the externally observed plantar flexion angles during the pointing movement, the independent variables were dance shoe (four levels: barefoot, split-sole jazz shoe, full-sole jazz shoe, and jazz sneaker). A single factor with four levels repeated-measures design was thus created with three primary dependent variables, maximum ankle, midfoot and metatarsophalangeal (MTP) joint plantar flexion.

Sixteen female recreational dancers aged 9.7 ± 1.4 years were recruited from dance schools in the Sydney metropolitan area. The number of subjects required for this study was calculated from previous data (O’Meara, et al., 2008) for an estimated power of 0.8, \( \alpha = 0.05 \). Subjects were included if they currently participated in jazz class or were dancers familiar with wearing jazz shoes. Each subject had the dance shoes fitted on the day of testing and the shoe size recorded. All subjects and their parents gave informed consent and completed a participant information sheet and a short questionnaire about the subject’s current dance class workload and the shoe types they used. All subjects and their parents were informed that they could withdraw from the study at any time. The University of Sydney Human Research Ethics Committee approved the study protocol (ref. no. 04–2009/11606).

Data were collected at a frame rate of 100 Hz using a 14-camera motion analysis system (Motion Analysis Corporation, California, USA). Retro-reflective markers were placed on the bony landmarks to define the three-dimensional position and orientation of the pelvis, thigh, shank, and foot. The hallux was modeled with two markers. For the shoe conditions, the bony landmarks were palpated through the shoe and the markers were placed on the outside of the shoe in the corresponding position (Gorton, et al., 2009; Wrbaškić & Dowling, 2007).

Subjects were placed in a reference position standing erect with arms straight, abducted to shoulder height, palms facing down and feet parallel, forward facing along the x-axis of the laboratory. The movement sequence was explained to the subject [Table 1] and ample time to practice the movement was allowed until they were comfortable and familiar with the sequence. A metronome (Nikko Seiki Co. Ltd., Japan) set to 100 bpm was used to set the tempo of the movement and subjects practiced the movement sequence both with and without the metronome. Subjects were given standardized instructions to “point their feet as best they can each time,” not to transfer weight onto the plantar flexed foot, keep the knees straight at all times and to use their arms for balance as they wished.

The four shoe conditions (Figure 1) were randomly ordered for each of the subjects (www.randomization.com).

1. Barefoot, the control condition within each subject.
2. Full-sole jazz shoe, Jazzlite, S0402L (Bloch, Australia). Leather construction with laces and a full rubber outsole.

![Figure 1](https://example.com/figure1.jpg) — Jazz shoes: Lateral view of right shoe and plantar view of left shoe. A = jazz sneaker, B = full-sole jazz shoe, C = split-sole jazz shoe.

<table>
<thead>
<tr>
<th>Metronome Clicks</th>
<th>Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2</td>
<td>Slide right foot anteriorly to maximal plantar flexion toe on floor</td>
</tr>
<tr>
<td>3, 4</td>
<td>Dorsiflex foot maintaining the position of the lower limb in the air</td>
</tr>
<tr>
<td>5, 6</td>
<td>Plantar flex foot maximally toe touches floor</td>
</tr>
<tr>
<td>7, 8</td>
<td>Slide foot back returning to start position</td>
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</tbody>
</table>
3. Split-sole jazz shoe, Elastabootie, S0499 (Bloch, Australia). Leather construction with elastic inserts on the sides and a “split” ethylene vinyl acetate outsole, with separate forefoot and rearfoot sections.

4. Jazz sneaker, Classic Boost, S0538L (Bloch, Australia). Made from a combination of synthetic materials with laces and a split outsole.

To control the lacing system tension of the full-sole jazz shoe and jazz sneaker, a spring-loaded scale (Ohaus Scale Corp, Florham Park, NJ, USA) was used to ensure the laces were all tightened with the same 30 N force.

The identification and continuity of marker trajectories were ensured using the motion analysis system and then imported into kinematic analysis software (Kintrak, University of Calgary, Canada) where the data were filtered with a dual-pass Butterworth filter set at a cut-off frequency of 3.3 Hz. Kintrak was used for segment definition and angle calculation. Orthogonal axes were embedded in the shank, rear foot, and forefoot segments (Figure 2). From these axes, joint coordinate systems were constructed for the toe, midfoot and ankle, according to International Society of Biomechanics standards (Wu, 2000). Ankle plantar flexion angle was measured between the shank and the rearfoot, midfoot plantar flexion angle measured between the rearfoot and the forefoot, and the MTP plantar flexion angle measured between the forefoot and the end of the hallux. Files were analyzed in Microsoft’s Excel to obtain the maximal plantar flexion angles for each of the separate joints (ankle, midfoot and MTP) in each trial (Figure 3). The best of the five trials was taken as the subject’s maximal plantar flexion angle for each individual joint.

A shoe dynamometer (Nambiar, 2006) was used to measure the torque required to bend the selected shoes in the sagittal plane at the points corresponding to the MTP joint and the midfoot region. The shoe was placed on the force plate as shown in Figure 4. The rear clamp was placed inside the heel counter when measuring stiffness at the midfoot joint region and placed in the midfoot section of the shoe when measuring stiffness at the MTP joint region. The axis of plantar flexion, midfoot or MTP joint was aligned with the edge of the force plate. An inclinometer (LS160, The Laser Depot, S.A. Australia) was placed on top of the front section of the shoe. The shoe was moved through 40° of plantar flexion (based on the motion analysis testing) or the full range of motion allowed by the shoe, whichever came first, for the MTP and midfoot joints. The torque required to bend the shoe was recorded using a custom force platform (four X-Tran load cells, model k4W-750N, Applied Measurement Australia Pty Ltd. Vic, Australia). Nonlinearity and hysteresis were less than 0.03%.

A school shoe (Size 3, Clarks, Australia) and thongs (flip-flops, size 33/34 Havaianas, Brazil) were tested in the shoe dynamometer to provide a frame of reference for the stiffness values of the jazz shoes. Each shoe was taken off the force plate after each trial and the variability of the results used to ascertain reliability of the measures. The size of the shoes tested in the shoe dynamometer corresponded to the average shoe size (Bloch size 6) taken from the motion analysis testing.

Data were collected at a rate of 60 Hz for 30 s per trial. The data were then extracted using Matlab (custom software developed using Matlab, Mathworks Inc., USA) and Excel. The stiffness of the shoes was calculated as the gradient of the slope during plantar flexion. The reliability estimate of the shoe stiffness measurements was taken from the calculation of the standard error of measurement.

For the kinematic analysis, repeated measures analysis of variance was used to test for significant differences (threshold statistical significance set at \( p < .05 \)) in the primary outcome variables that were due to the independent variables with a Bonferroni adjustment for
multiple measures. The exact p-value was reported and discussed for its relevance together with the effect size ($\eta^2$) and the observed power.

For the mechanical testing, an analysis of variance was performed to test for significant differences in the primary outcome variable, shoe stiffness, that were due to the independent variables. A Bonferroni adjustment was performed for the post hoc analysis to determine the differences between the individual shoes ($p < .008$).

**Results**

The statistical analysis of the overall effect of the shoe on ankle kinematics, taking all variables into account, showed a power of 1.00 ($p < .001$, effect size = 0.59); therefore, a sufficient number of subjects were recruited for this study. The overall ANOVA showed the dance shoes had a significant overall effect on ankle plantar flexion ($p < .001$) and midfoot plantar flexion ($p < .001$), but did not have an overall effect on the MTP plantar flexion ($p = .143$).

For the ankle kinematic data, post hoc analysis of ankle plantar flexion revealed no significant difference in the degree of ankle plantar flexion between barefoot and split-sole jazz shoe conditions ($p = .151$), whereas the difference between barefoot and jazz sneaker ankle plantar flexion should be noted, $p = .053$. The full-sole jazz shoe showed significantly greater plantar flexion angle of the ankle ($46.81 \pm 1.83^\circ$) when compared with the jazz sneaker ($41.66 \pm 1.44^\circ$, $p = .002$), the split-sole jazz shoe ($41.11 \pm 1.70^\circ$, $p = .002$) and the barefoot condition ($36.69 \pm 2.07^\circ$, $p < .001$). No significant difference in ankle plantar flexion angle was found between the split-sole jazz shoe and jazz sneaker conditions ($p = 1.00$) (Figure 5).

For the midfoot kinematic data post hoc analysis of midfoot plantar flexion showed the barefoot condition displayed a significantly greater amount of plantar flexion at the midfoot ($36.45 \pm 1.46^\circ$) when compared with all the jazz shoes ($p < .001$) (Figure 6). The split-sole jazz shoe
(22.41 ± 1.25°) had significantly greater plantar flexion at the midfoot when compared with the jazz sneaker (15.92 ± 1.39°, p = .001) and full-sole jazz shoe (10.93 ± 0.76°, p < .001). The angle of midfoot plantar flexion was significantly greater in the jazz sneaker when compared with the full-sole jazz shoe (p = .009).

For the shoe stiffness testing, the jazz shoes tested in the dynamometer were size 6 (manufacturer’s sizing), equivalent to a size 3 school shoe and size 33/34 thongs. The separate forefoot and rearfoot sections of the outsole in both the jazz sneaker and the split-sole jazz shoe were designed to be highly flexible. The stiffness values at the midfoot region were negligible and below the resolution of the force platform. Therefore, these jazz shoes were classified as more flexible than the other shoes and eliminated from the statistical analysis.

The shoe stiffness results at the MTP joint region showed that the school shoe (0.176 ± 0.069 N·m) was significantly stiffer than the full-sole jazz shoe (0.010 ± 0.001 N·m, p = .006), the thongs (0.015 ± 0.003 N·m, p = .006) and the split-sole jazz shoe (0.010 ± 0.003 N·m, p = .006). The jazz sneaker (0.048 ± 0.017 N·m) was significantly stiffer than the full-sole jazz shoe (p = .008), but not significantly different to the school shoe, the split-sole jazz shoe or the thongs (p > .008). The full-sole jazz shoes were not significantly stiffer than the split-sole jazz shoes (p = .816), neither were the thongs when compared with split-sole jazz shoes (p = .053). The thongs were not significantly stiffer at the MTP joint region than the full-sole jazz shoes (p = .011) (Table 2).

The school shoe (0.082 ± 0.014 N·m) was significantly stiffer at the midfoot joint region than the full-sole jazz shoe (0.003 ± 0.001 N·m, p < .001) and the thongs (0.011 ± 0.002 N·m, p < .001). The thongs were found to be significantly stiffer than the full-sole jazz shoes (p < .001).

The shoe stiffness measurements were reliable with low standard error scores (Table 2). The midfoot measurements had a standard error of 0.05 N·m for the school shoe, 0.01 N·m for the full-sole jazz shoe and 0.02 N·m for the thongs. The MTP joint region measurements had a standard error of 0.02 N·m for the full-sole jazz shoe, 0.02 N·m for the thongs, 0.03 N·m for the split-sole jazz shoes and 0.06 N·m for the jazz sneaker. The school shoe showed variability across the trials for the stiffness at the MTP region of the shoe, appearing to increase in flexibility with each trial, which was reflected by the standard error of 0.12 N·m.

### Table 2 Shoe stiffness measured by shoe dynamometer as torque (N·m) required to bend each shoe in the sagittal plane at the equivalent midfoot and metatarsophalangeal (MTP) area, mean ± SD

<table>
<thead>
<tr>
<th>Shoe Type</th>
<th>Midfoot Stiffness (N·m)</th>
<th>MTP Stiffness (N·m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>School shoe</td>
<td>0.082 ± 0.014</td>
<td>0.176 ± 0.069</td>
</tr>
<tr>
<td>Thongs</td>
<td>0.011 ± 0.002</td>
<td>0.015 ± 0.003</td>
</tr>
<tr>
<td>Full-sole jazz shoe</td>
<td>0.003 ± 0.001</td>
<td>0.010 ± 0.001</td>
</tr>
<tr>
<td>Split-sole jazz shoe</td>
<td>N/A</td>
<td>0.010 ± 0.003</td>
</tr>
<tr>
<td>Jazz sneaker</td>
<td>N/A</td>
<td>0.048 ± 0.017</td>
</tr>
</tbody>
</table>

Note. N/A = not available, as below the resolution of shoe dynamometer.

Discussion

The dancers displayed a significantly greater observed ankle plantar flexion angle in the full-sole jazz shoe, and showed significantly reduced observed plantar flexion at the midfoot in all jazz shoes, while a significant effect on the observed MTP joint plantar flexion was not found in any of the jazz shoes. For the best aesthetic of the pointed foot, the angle of plantar flexion achieved while wearing dance shoes should ideally be the same angle of plantar flexion achieved when barefoot. The split-sole jazz shoe was the best dance shoe to achieve this goal, providing adequate movement at both the midfoot and MTP joints. To perform maximal plantar flexion of the foot and ankle the footwear worn for dance must provide minimal resistance. Despite the jazz sneaker having the same split-sole design, the thick forefoot section of the jazz sneaker contributed to the increased stiffness and hence significantly lowered MTP plantar flexion.

From the motion analysis testing, we found that the midfoot region was capable of up to 40° of plantar flexion and all of the jazz shoes allowed this range of motion with minimal resistance when assessed without the foot. The plantar flexion angles achieved at the midfoot during motion analysis testing were all significantly different between all shoe conditions. Despite the split-sole design, that seems to improve the aesthetic of the pointed foot, the split-sole jazz shoe restricted midfoot plantar flexion by approximately 50% and the jazz sneaker restricted it further. The split-sole design was significantly better than the full-sole jazz shoe at allowing a greater plantar flexion angle at the midfoot because the shoe stiffness values for the split-sole shoes were so small they were even below the resolution of the shoe dynamometer. In addition, the jazz shoes allowed the range of motion achieved at the MTP joint, although with a large resistance. Consequently, it would be interesting to investigate whether there is any benefit or disadvantage in a shoe that restricts this motion.

Although statistically the dance shoes did not have an overall effect on MTP plantar flexion, closer examination of the data indicates a restriction in MTP plantar flexion with the jazz sneaker and full-sole jazz shoe compared with the barefoot condition. The lack of statistical significance was due to the large variability in MTP plantar flexion in the barefoot condition. This variability could be due to individual variation in technique, dance standard or strength of the intrinsic foot muscles and/or human variability in this sample. The stiffness of the dance shoes at the MTP joint decreases this variability. Although the full-sole and split-sole jazz shoes were not
significantly different in MTP region stiffness, the MTP plantar flexion angle achieved in the split-sole jazz shoe was significantly greater than in the full-sole jazz shoe. This appears to be due to the split-sole design that allows the forefoot section to move downward as a whole rather than bending exactly at the MTP joint during plantar flexion. This could explain why the difference in angle at the MTP joint is so small between the split-sole jazz shoe and the barefoot condition.

The results of this study have implications for dance technique with the requirement of maximally plantar flexed feet in jazz and ballet. The stiff jazz shoes restricted foot motion, which could lead to a change in muscle recruitment; similar to findings in running shoe research (Atwells & Smith, 2000; Nigg, et al., 2003; Wakeling, et al., 2002). The restriction of MTP plantar flexion could lead to excessive recruitment of the interphalangeal joint flexors, a clawing action, in order for the dancer to achieve maximal plantar flexion. This movement is not allowed in jazz or ballet technique. The stiffness of the jazz shoes may allow the foot to slide inside the shoe during plantar flexion. Whether the toes are plantar flexing properly or clawing cannot be seen if the foot moves within the shoe. With a stiff dance shoe, the dancer cannot display their true plantar flexion capability. For teachers, this could mean being unable to see the child pointing their feet as best they can or to detect incorrect technique. Practicing any form of improper technique from a young age could have an effect on injury risk (Bowling, 1989; Denton, 1997; Milan, 1994; Quirk, 1994; Schoene, 2007; Solomon & Micheli, 1986) as the dancer gets older and increases their workload (Purnell, et al., 2006).

From the motion analysis data we found that there appears to be a relationship between observed plantar flexion angles at the foot and ankle where greater plantar flexion in one joint (ankle) is associated with less plantar flexion in other joints (midfoot and MTP). In this study, the barefoot condition had the most midfoot and MTP plantar flexion but the lowest ankle plantar flexion. However, the trial at which maximal ankle plantar flexion occurred was not necessarily the same trial that either maximal plantar flexion of the midfoot or MTP joint occurred. Further investigation could result in dancers choosing a shoe design that enhances the areas of the foot, which have greater natural range of plantar flexion to produce a better looking point overall.

The restriction of midfoot and MTP joint motion has implications for the growth and development of dancers’ lower limbs. If greater plantar flexion in one joint (for example, the ankle) is causally linked with less plantar flexion in other joints by shoe action, there may be consequences for lower limb development and performance. This is important for dancers because the feet need to be strong (Denton, 1997; Novella, 2000; Spilken, 2007; Stretanski & Weber, 2002). By wearing a particular style of training shoe that reduces the load on the extrinsic plantar flexors, the intrinsics may be encouraged to correctly plantar flex the toes leading to increased strength and power of the foot muscles. Articulation of plantar flexion through the ankle and foot facilitated by the footwear, may also improve jump height.

The concept of selecting dance shoes that best facilitate foot movement can be applied to dance injury management. For example, posterior ankle impingement occurs due to the excessive plantar flexion required in dance. Reducing the load on the posterior ankle by increasing the degree of plantar flexion allowed at the midfoot and MTP joint could potentially reduce the risk of posterior ankle injury (Dozzi, et al., 1989; Galea, 1985).

The primary aim of this study was to quantify the externally observed angle of plantar flexion in various jazz shoes; therefore, the markers were placed on the outside of the shoe. This, however, resulted in a number of study limitations. External marker placement may not be as accurate as placing markers on the skin and limits our findings to the shoe motion or external observed angle instead of foot motion. However, cutting holes in the shoe to place markers directly on the bony landmarks could compromise the integrity of the shoe structure and alter the shoe mechanics. In the future, fluoroscopy could provide a different perspective to detect any additional movement of the foot inside the shoe. This study only examined the effect of the jazz shoes on plantar flexion. Future research could investigate the shoe–foot technique interface for the effect of the jazz shoes on the other planes of movement. This study also only examined the effect in young dancers; future investigations into the effect of dance shoes on plantar flexion should be done to ascertain if the results from the current study are applicable to adult professional dancers. Another limitation of this study was the sensitivity of the shoe dynamometer, which could not detect the stiffness of the highly flexible midfoot regions of the split-sole jazz shoe and jazz sneaker. Further development of the shoe dynamometer to increase its sensitivity will mean that more shoes that are flexible can be tested and compared.

This study provides some direction for jazz shoe design in the future. A shoe could be designed to emulate the movement of the foot, with similar degrees of plantar flexion at the ankle, midfoot and MTP joint. Perhaps additional divisions in the outsole to allow for increased plantar flexion will assist the dancer to achieve a better aesthetic for dance.

The results from this study showed that when wearing stiff jazz shoes, a small restriction in plantar flexion at the MTP joint and a greater restriction at the midfoot occur. This will decrease the aesthetic of the pointed foot and may encourage incorrect muscle activation. These restrictions will have an impact on the dance performance and aesthetic.

References


