Summer 7-2018

Rehearsal Injuries in Soft-Soled Character Shoes: Injury Rate of Female Collegiate Dancers Wearing Soft-Soled Character Shoes with 2.5 or 3.0 Inch Heels in Musical Theatre Rehearsals

Evelyn Vaughan
Honors College, Pace University

Injury Rates of Female Collegiate Dancers Wearing Soft-Soled Character Shoes with 2.5 or 3.0-Inch Heels in Musical Theatre Rehearsals.

Evelyn Vaughan

Faculty Thesis Advisor: Professor Ginger Cox

Pace University

Abstract

High-heeled shoes (HHS) have been known to present biomechanical imbalances in lower-leg mechanics at the pedestrian level, but have not been thoroughly studied in the context of highly dynamic movement, such as dance. In order to analyze the effects of 2.5-inch and 3.0-inch soft-soled character shoes (CS) worn by female collegiate musical theatre dancers during rehearsals, selected subjects completed a written questionnaire, the star balance excursion test, and a heel raise test. It was predicted that both heel heights would promote irregularities in subjects' sense of balance and lower leg stamina, while 3.0 inch CS would cause greater rates of injury overall. The resulting data showed that while there was no difference in the number of reported injuries among subjects wearing either 2.5-inch CS or 3.0-inch CS during rehearsals, there was less range of motion (RoM) and stability observed in 3.0-inch CS. The median number of heel rises from the heel raise test was approximately 10, showing a wide range of strength and stamina among subjects individually. Additionally, only 35% of subjects reported warming up in CS before rehearsals, and 13% reported cooling down after dancing in rehearsal. These results indicate a great need for supplemental strengthening for dancers, as well as the development of a comprehensive warm-up and cool-down aiming to prepare dancers to effectively wear CS for extended periods of time and continue to counter potential injury.

Keywords: soft-soled character shoes, collegiate dancers, star excursion balance test, heel raise test, range of motion, stability, strength, injury rate

Background

Codified ballet technique, identified as ballet methodology that "follows a sequentially progressive syllabus . . . that addresses the training goals and objectives from which barre and center exercises are constructed," has formed a standard of strength and flexibility that students must acquire before attempting pointe work.[1] The first few years of training in pointe shoes are spent further developing young dancers' feet, ankles, and calf strength to support the extreme states of plantar flexion and pressure required for dancing *en pointe.*[2] There is quite a significant amount of literature surrounding injury and injury prevention for professional ballet dancers *en pointe* compared to the very small number of dancers who are able to enter and succeed in the professional ballet industry. Musical theatre dancers must also achieve high levels of strength, flexibility, and stamina in order to sustain their own professional careers. However, there has been little to no research conducted on musical theatre dancers, whose careers span Broadway, the West End, Radio City Music Hall, various regional theatres, developmental labs, amusement parks, and cruise ships, among others.[3]

Female dancers pursuing a professional career in musical theater often transition from dancing in flat jazz shoes to soft-soled character shoes (CS) at the collegiate level. This is comparable to a young dancer progressing from soft ballet shoes into pointe shoes. However, unlike pointe work, there is no generally accepted training regimen within the dance community that successfully prepares dancers for careers in CS, despite the intense physical demands of rehearsing in shoes with an elevated heel.

It is widely recognized that high-heeled shoes (HHS) cause biomechanical irregularities within the body.[4-10,20] HHS are usually constructed to have a smaller area of contact with the ground at the heel, shifting the body's weight forward onto the forefoot. Pressure on the forefoot can increase dynamically as the heel height increases, quintupling peak pressure values in midfoot joints.[4] One dance-based experiment studied Latin ballroom dancers' weight placement and impulse force while dancing in various heel heights. As heel height increased, heel pressure was redistributed to the forefoot, specifically to the big toe and medial metatarsal.[5] The initial, barefoot pressure values doubled for both right and left medial metatarsals and big toes with the addition of 10 cm (4.9 inch) heels, increasing peak pressure by about 81% in comparison to barefoot data. This addition pressure alters the angles at which joints in the foot normally function, altering their ability to stabilize and support bodily movement.[5-7]

The ankle joint, or the talocrural joint, connects the distal ends of the tibia and fibula with the talus. This large, gliding joint creates three smaller joints (the tibiofibular, tibiotalar, and fibulotalar joints).[8] The four main muscles that control and stabilize the ankle joint include the peroneus longus, tibialis anterior, extensor hallucis longus, and the gastrocnemius (medialis and lateralis). The location of the center of pressure (CoP) depends on the muscles actively supporting the ankle joint in a given moment.[6,7] Additionally, the CoP moves in opposition to the center of mass (CoM) based on these specific muscle activations, resulting in bodily stabilization.[9] For example, activation of everting muscles (i.e. peroneus longus, gastrocnemius lateralis) moves the CoP medially while the CoM moves laterally. Under normal postural conditions, this is how the lower extremities stabilize the body. However, donning HHS complicates this process.

HHS require the lower limb muscles to be constantly active, causing a hike in energy consumption and greater risk of instability and/or injury. Alkjaer et al.[10] states that HHS increase the standing angle of plantar-flexion in the ankle (foot pointing down to the floor) by at least 15%. A constant state of plantar-flexion in the subtalar joint of the ankle forces lower leg muscles to contract within a smaller range of motion but at a higher frequency.[10,11] Consequently, HHS create an imbalance of muscle usage so that the gastrocnemius lateralis is initially engaged much more than gastrocnemius medialis. Moreover, the more time spent in HHS, the more the lateral head of the gastrocnemius decreases in energy output. Gefen et al.[6] found that during a heel raise test conducted with subjects who wore HHS regularly, normal lateral gastrocnemii functionality was reduced by approximately 45%. Consequently, the gastrocnemius medialis was left to compensate for its fatiguing counterpart, but continued to perform at only 80% of its initial functionality.[6,9]

Furthermore, intrinsic muscles that normally act as stabilizers are brought into the equation to make up for the overall lack of energy output from the main, extrinsic muscles, simultaneously compensating for decreased levels of balance *and* creating more instability.[6-10] If lower leg muscles are constantly working both extrinsically and intrinsically due to increased heel height, they may not be able to prevent dynamic eversion or inversion (rolling of the ankle). The risk of ankle inversion injuries have been specifically correlated to an increase in heel height, exacerbated by the fact that HHS also allow the ankle joint greater movement on the anterior plane.[7] In ankle flexion, the tibiofibular mortise that connects the talus with the tibia and fibula glides anteriorly, effectively narrowing the surface area of that talus dome. In dorsiflexion, that surface area widens. In an elevated heel height, however, a constant state of plantar flexion does not allow the talocrural to achieve full dorsiflexion, compromising the stability of the talocrural joint.[8] Muscular compensation for resulting instability at the ankle causes fatigue, defined as lower leg muscles' inability to properly stabilize and "maintain a reasonably expected force output."[6,11] This puts individuals who often wear HHS at greater risk of injury.

Additionally, researchers suggest that wearing high heels may accelerate the shortening of the calf muscle, permanently limiting range of motion in the ankle joint.[10] Mechanically speaking, walking in HHS co-activates the soleus and tibialis anterior muscles, which in turn over-engages the ankle joint muscles and dorsal/ plantar flexors. Soleus activity in HHS has been known to increase by 95% in comparison to barefoot walking ($p=.035$).[10] This causes the ankle joint and the Achilles tendon to stiffen, which actually becomes an additional source of ankle stability.[7,9,10] As a result, the RoM of both the ankle and lower leg musculature decreases.

All of these observed changes in muscle activation between barefoot and high-heeled gaits suggest separate motor control strategies for both scenarios. Alkjaer et al.[10] suggests that the central nervous system is open to sensory feedback, based on the increase in soleus muscles' reflexes during the swing phase of walking in HHS; a higher heel height also induces local nerves to become more sensitive as yet another means of compensating for the lack of a stable ankle joint position. Taking in a heightened amount of information creates more degrees of freedom for the body to control, explaining how HHS elicit more movement variability. There is a lack of control and responsiveness in a joint that is subjected to extended periods of muscle fatigue and passive motion, two factors heavily associated with extensive wearing HHS.[3,7]

These compensations for HHS naturally require greater energy expenditure to yield the same levels of activity as one would achieve with less effort in bare feet. Ebbeling et al.[9] found that ventilation rates jumped from 10.7 ml/kg/min walking on the treadmill on flat to 11.3 ml/kg/min in 2 inch heels and 12.1 ml/kg/min with 3 inch heels. Similarly, Li et al.[11] compared energy consumption rates of females jogging on a treadmill for 15 minutes in various heel heights. Subjects burned an average of 4.8 kcal/min jogging in a flat heel and 5.52 kcal/min in 1.75 inch HHS, an 18.42% increase in energy expenditure.[11] The 2.7 inch high heel shoes yielded around 6.46 kcal/min, an 11% increase from the 1.75 inch HHS. Both research teams concluded that maximum energy cost occurred between the flat and low heels; it may be that simply shifting the foot from a flat-footed position to a plantar-flexed state is enough to alter muscular function, rather than the height of the heel itself.[9,11] Ebbeling et al.[9] specifically suggested that wearing HHS 2.0 inches or higher would be disadvantageous to wearers, as they were not optimal for energy cost nor for functionality of the lower extremities.

Based on this data, it can be deduced that those accustomed to wearing HHS must develop adapted lower leg biomechanics in order to make up for the additional energy needed to sustain adequate levels of mobility and stability. This is especially applicable to musical theatre dancers, who often wear a dance shoe with a heel during highly dynamic movement. For example, completing a classic leap requires dancers to land “toe-ball-heel,” rolling through the entire foot to a bent knee in order to effectively diffuse the impact of the jump. While most trained dancers are completely capable of doing this in bare feet or with a flat ballet/jazz shoe, the coordination needed to achieve a proper landing is compromised when soft-soled character shoes (CS) are added to the equation. The nature of HHS does not allow the body to compensate for the added forefoot pressure via diffusion of force; momentum decreases from the heel area of the foot with added heel height and does not allow the dancer to roll through the foot entirely, taking all of the impact onto the forefoot, as mentioned before. Additionally, researchers have found that as heel height increases, a significant timing gap forms between lower extremities joints' maximum support phases; in 3.0 inch heels a 30% difference between the knee and the calcaneus timing has been noted, which could lead to serious injury during dynamic movement.[9]

The results of only a few of these studies may be comparable to dancing in CS, as most researchers do not take into account impact and energy consumption as a result of activity being performed in high heels. The majority of the studies referenced above are also based on pedestrian movement (i.e. walking, standing, jogging) and only reference movement taking place in the anterior and posterior directions. Evans et al.[12] did gather information pertaining to injuries sustained by professional musical theatre performers in the West End. Of all the performers surveyed, 52% of dancers' injuries were located in the lower extremities: 18.5% reported ankle injuries and 16.5% reported knee injuries. It was determined that female performers were more likely to sustain injuries than male. The researchers concluded that while "an explanation [was] not known, wearing high-heeled shoes may contribute [to female injury rates]."[12] However, it was noted that injury rates could be exacerbated by raked stages. Here, parallels can be drawn between the effects of sloped stages and HHS: they both pitch performers forward in their bodies, causing their CoM to shift backwards to counter the shift of their CoP onto the forefoot, therefore disrupting normal standing posture.

Clearly, there is a need for more research surrounding musical theatre dancers who wear heels. It would be prudent to study collegiate dance students and their training methods in CS, especially regarding the point at which heel height becomes detrimental to a dancer's well-being. In a conservatory-style university dance program, dance students spend 9-12 hours per week for about 9 months per year training in dance styles including contemporary, modern, ballet, jazz, hip hop, tap, and theatre.[13] Respectively, these styles are done in bare feet, flat ballet and jazz shoes, sneakers, and low-heeled tap shoes. Only in theatre dance do females consistently wear CS, but very little warm-up that is spent physically in the shoes is provided. Instead, students typically warm-up in bare feet or in jazz shoes and female dancers don CS midway through class in time for across-the-floor technique, center combinations, and/or choreography.

Female collegiate dancers wear CS with the most frequency and consistency in musical theatre-based rehearsal processes, which take place outside of normal technique classes.[13] Dancers arrive at rehearsals from other university courses and often do not have time to warm up and physically prepare themselves for high-energy, intense rehearsal processes. What is more, a rehearsal process for a performance piece takes place over a span of 3 weeks to a month, with 2-4 rehearsals per week. This equates to 6-12 hours of rehearsal per week consistently for about a month, all of which may be in CS. This is an intense period of dancing on top of conservatory-style university training during the day.[13] This volume of dancing aligns with American Ballet Theatre's definition of overtraining, a leading factor of burnout and increased risk of injury.[2]

It is important that dancers' training reflects their performance circumstances so that they are show-ready. Professional dancers, particularly those who perform in shows with demanding choreography, are 2.1 times more likely to become injured in comparison to actors.[12] Due to the lack of support for formal training in elevated heel heights at a pre-professional level, rehearsing musical theatre dance pieces in CS may generate greater muscular imbalances due to dynamic variability, creating more room for potential injury.

Purpose/ Hypothesis

The objective of this study is to address the effects of rehearsing in CS as a cause of injury by comparing two different heel heights worn by collegiate female dancers and their subsequent injury rates during musical theater rehearsals. Do female collegiate dancers between the ages of 20-22 who rehearse for at least 6-12 hours per week within a rehearsal period of at least one month in CS experience greater rates of injury in a 2.5-inch or a 3.0-inch heel? The biomechanics of this eccentric, partially plantar-flexed state redistributes heel pressure further on to the forefoot, alters lower leg muscular function, and creates more degrees of freedom in the anterior ankle joint.[4,6,9,11] Therefore, I predict that both heel heights will demonstrate irregularities in subjects' sense of balance and lower leg stamina, while 3.0-inch CS causes greater rates of injury compared to 2.5-inch CS within a rehearsal process timeline.

Methods

Participants

This study involved 23 female collegiate dance majors attending Pace University. Females were studied exclusively as it is a commonly accepted norm in the musical theatre dance industry that females perform in CS. Subjects were between the ages of 20 and 22, of multiple ethnic backgrounds, and currently uninjured. Subjects had at least two years of experience dancing in CS and had participated in musical theatre rehearsals within that time period.

Measures

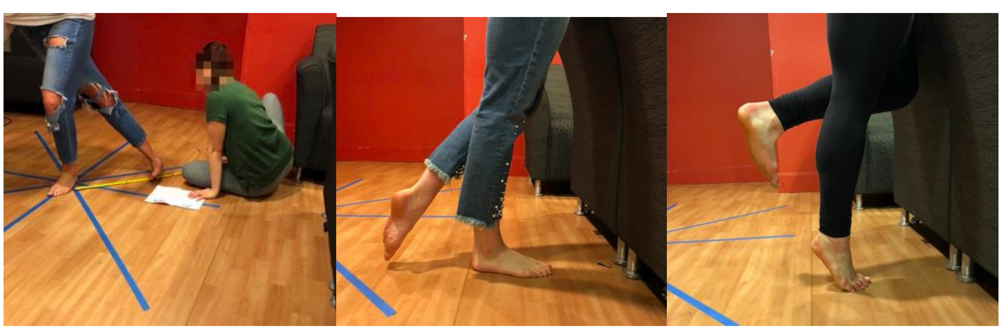
To initiate voluntary subject selection, an announcement was posted on the Pace University Commercial Dance Department's private Facebook group. The post included general information about the study and requested that interested individuals email the investigators for more information. Any replies received by the co-investigator were sent an email with additional information, as well as a consent form. Subjects who confirmed their interest and returned the sign consent form were assigned a numerical identifier that represented them throughout the study (see Appendix).

The initial procedure within this study was a written questionnaire administered to subjects via an online Google Form. Questions prompted subjects to report the height of the heel they were accustomed to dancing in, the volume of rehearsals they participated in within the last 2 years that required CS, past injuries that occurred during these rehearsals, whether or not subjects regularly warm up in CS prior to rehearsals, and if they regularly cool down after rehearsals in CS (See Appendix). 2.5-inch and 3.0-inch CS were used in this study as they are the most popular and commercially available shoes for musical theatre dancers. All CS reported on within this study were of the same brand and were personally provided by the subjects. In a university setting, a standard rehearsal period is roughly 6-12 hours a week for 3 consecutive weeks, not including performances.[13] Injury, in this study, is defined as any rehearsal-related incident resulting in physical strain and/or damage to the subject.

The second part of the procedure was a physical test, comprised of the star excursion balance test (SEBT) and a heel raise test. The physical portion of the study was administered at Pace University by the co-investigator and took subjects about 8 minutes to complete per subject.

The SEBT can measure and predict deficits in the lower extremities in terms of balance, ankle strength, flexibility, and stamina.[14,15] In order to complete the test, subjects stood with one foot in the middle of a taped "star." They were then asked to extend their free foot out as far as they could to each direction (anterior, anteromedial, medial, posteromedial, posterior, poster lateral, lateral, anterolateral) denoted by the tape (Image 1). Subjects were encouraged to *plié*, or bend their supporting leg, in order to achieve a further extension of their moving leg, as long as they did not displace their body weight off of the supporting leg. Each extension was measured in inches from the supporting foot to the heel of the extended foot. Subjects completed the SEBT on the right and left, both in bare feet and in their CS in order to compare levels of dynamic-postural ability. Each subject's completion of the SEBT was filmed in order to study supporting foot stability and strength. The resulting data points were split into two groups: subjects who wore 2.5-inch CS and those who wore 3.0-inch CS. The averages of each direction on flat were subtracted from the averages in each direction in heels, resulting in values that demonstrate the differences in ankle flexibility between those subjects in 2.5-inch CS versus 3.0-inch CS.

Image 1 The SEBT test (a) and the heel raise test (*relevé* without *plié* between) (b-c)



(a) (b) (c)

The barefoot heel rise test measures the strength and endurance of the gastrocnemius and soleus muscles (*triceps surae*), which facilitate raising and lowering on the balls of the feet (*demi-pointe*).[16,17] The standard number of heel rises is 25 for people with no physiological irregularities,[16] while the determining number for dance students interested in beginning to train *en pointe* is 20.[17] This test was used to determine the strength of subjects' triceps surae because the eccentrically-supported plantar-flexed state of the ankle does not allow the *triceps surae* to contract and release fully between full *demi-pointe* and flat.[4,5,9] Thus, the *triceps surae* never fully releases until the HHS are removed, compromising lower leg muscle strength and stamina. Subjects were directed to stand facing a *barre* or table, which they could hold onto for support. Standing on one foot, they were asked to *relevé* to *demi-pointe* (rise up to onto the balls of their feet), then lower back down again without bending the supporting knee. They were instructed to do this as many times as they could on one foot until they felt they wanted/ needed to stop. The co-investigator recorded at what point subjects fatigued (i.e. wobbled, relied more heavily on the barre to complete a heel raise, did not achieve as high of a *demi-pointe* as prior heel raises, bent their supporting knee), as well as how many total heel raises were completed until self-selected termination. This test was completed on right and left feet.

Analysis

The reported heel heights worn by subjects were compared to the data collected from both the questionnaire and physical tests. Based on these comparisons, any irregularities that present themselves will be analyzed and will aid in a possible conclusion as to whether a 2.5-inch or a 3.0-inch heel height potentially leads to a greater rate of injury.

Results

Questionnaire

65% of subjects reported participating in 3 or more rehearsal processes in the past 2 years (Figure 2). While about a third of the subjects spent the expected 6-12 weeks out of the year in rehearsal processes, 39% reported rehearsing 28 or more weeks per year (Figures 3a). The same percentage of subjects also reported having 2 rehearsals per week, while 56% had 3 or more rehearsals per week of rehearsal (Figure 3b). The average length of a single rehearsal in CS was approximately 140 minutes. However, the median number of minutes per rehearsal was overwhelmingly 120 minutes (Figure 3c).

Figure 1 Distribution of subjects who consistently wore 2.5 inch CS and 3.0 inch CS during rehearsals

Figure 2 Distribution of dance numbers, or pieces, subjects participated in per year that required rehearsal

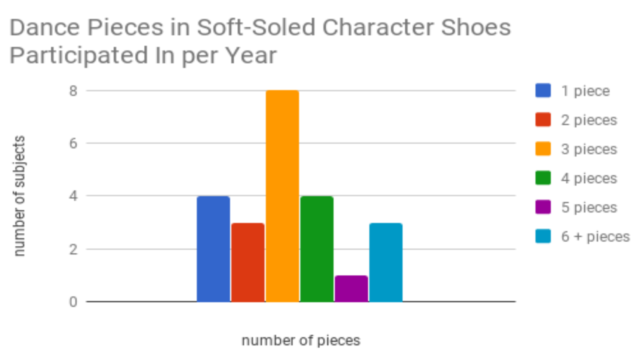
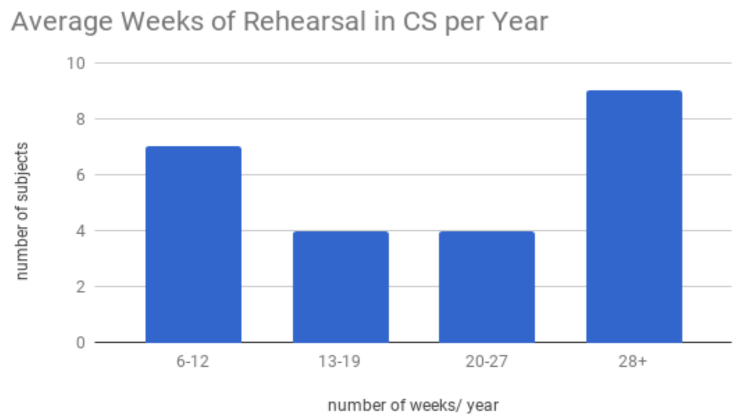
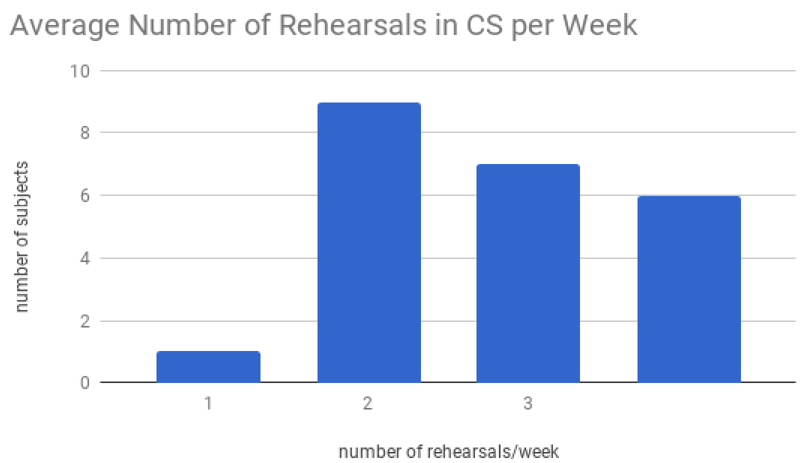


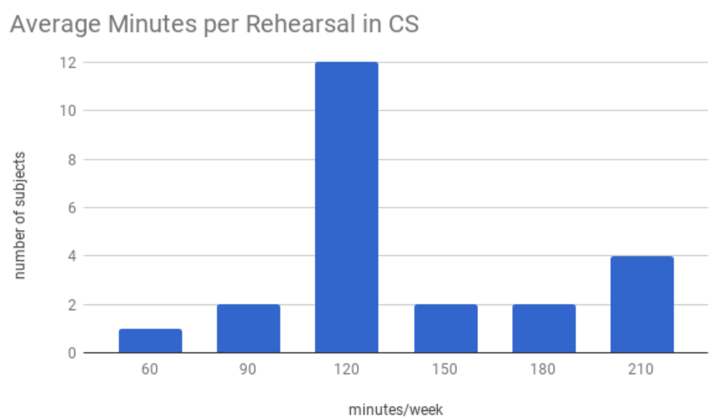
Figure 3 Distribution of average time spent in rehearsals in CS in weeks (a) rehearsals per week (b) and minutes per rehearsal (c)



(a)



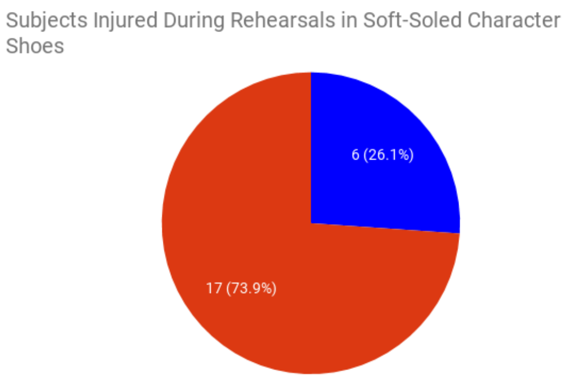
(b)



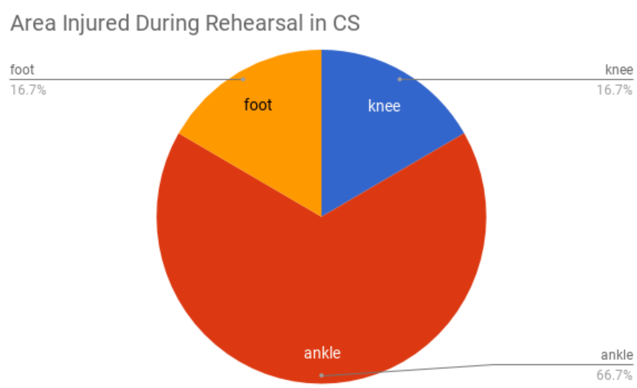
(c)

Of the 23 subjects who completed the questionnaire, 6 subjects (23%) reported 7 injuries that occurred while rehearsing in CS (Figure 4a). The ankle area was the most commonly injured (Figure 4b-c). Ankle injuries occurred evenly between subjects who wore 2.5-inch and 3.0-inch CS. Additionally, there were two foot injuries reported evenly between heel heights. One knee injury was noted, at the 3.0-inch heel height. Finally, 65% of subjects reported that they do not warm up in CS before rehearsal (Figure 9). Compared to the 34% of subjects that do warm up, only 13% confirmed that they cool down after rehearsal.

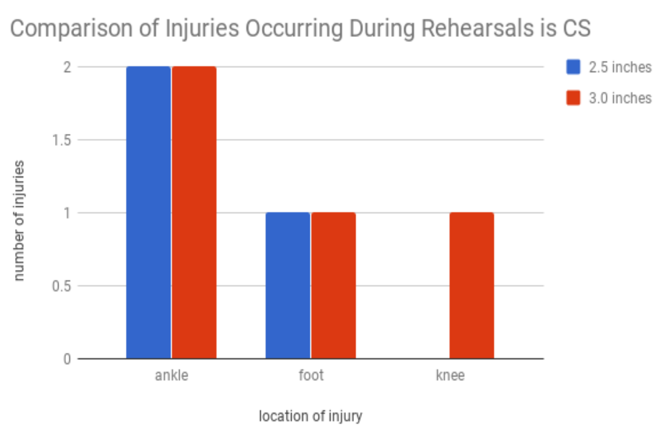
Figure 4 The percentage of subjects who reported injury during rehearsals in CS (a) areas injured of those subjects (b) and injuries occurring in 2.5 inch CS vs. 3.0 inch CS (c)



(a) red = uninjured
blue = injured

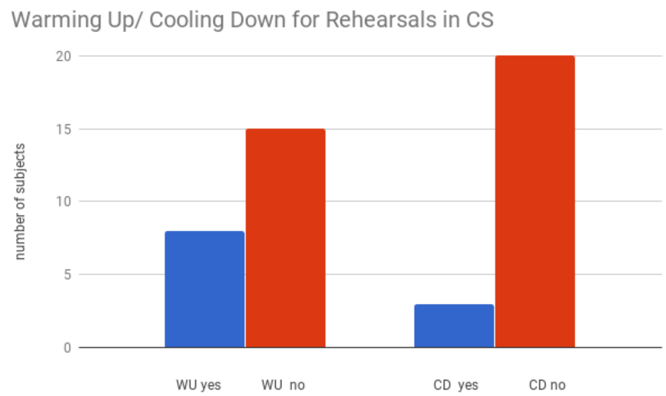


(b)



(c)

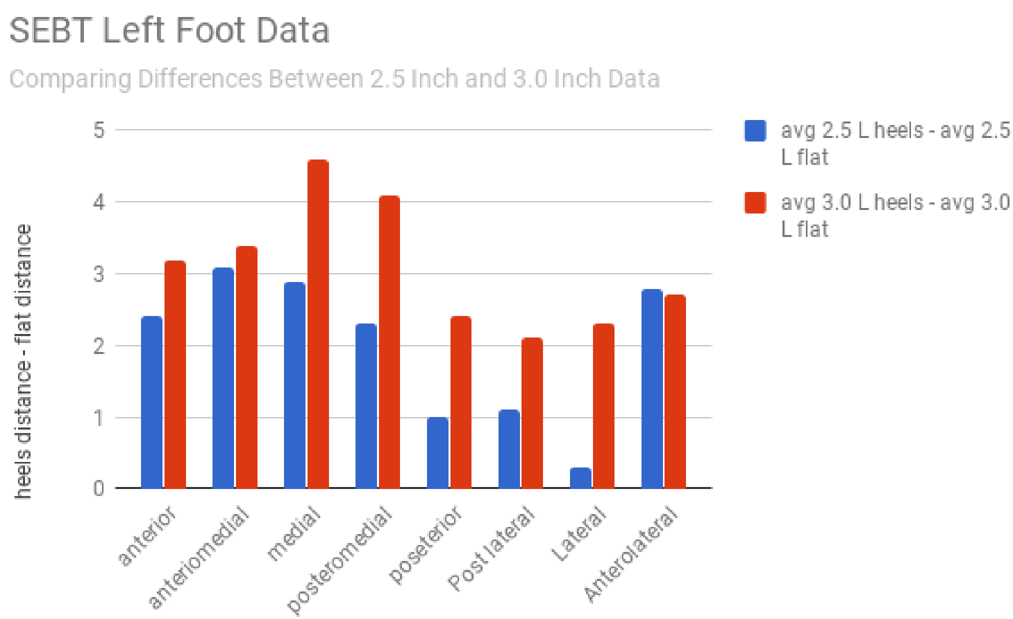
Figure 5 Number of subjects who reported warming up in CS before and cooling down after rehearsals. Blue = yes, Red = no



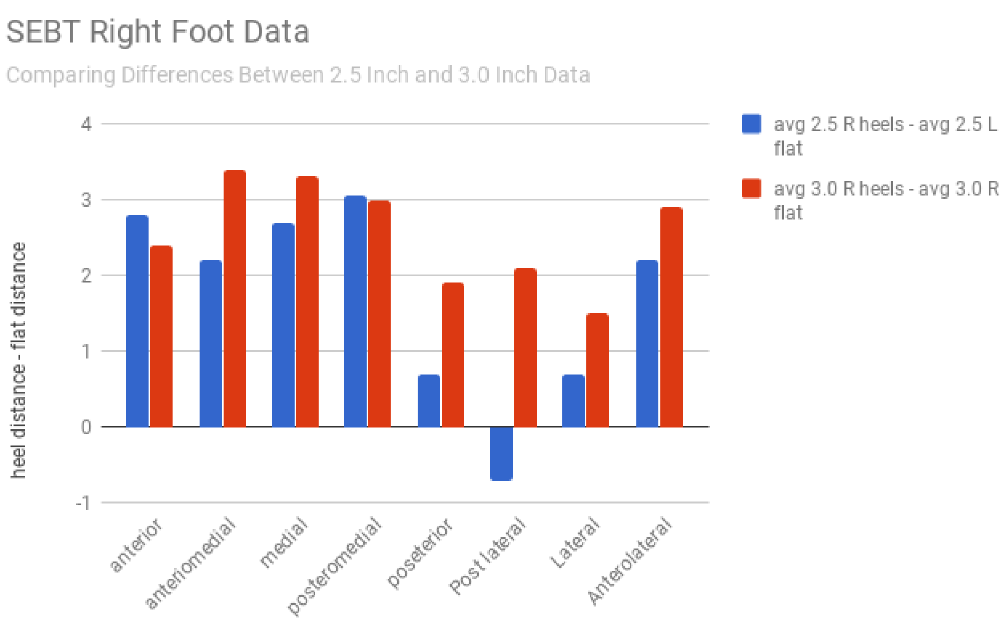
Physical Test

Based on the two graphs representing the SEBT results, it seems that the average difference in most directions between the distance reached in 3.0-inch CS and distance reached barefoot (red) was larger on average than the reported differences in 2.5-inch CS vs. barefoot (blue) (Figure 6). The largest differences occurred to the medial and posteromedial directions on the left for subjects wearing 3.0-inch CS. Though the resulting subtracted values for posterior, posterolateral, and lateral directions were overall lower to both the right and left in both heel heights, the 3.0-inch CS presented much higher differences than the 2.5-inch CS. Laterally, subjects in 2.5-inch CS exhibited almost no difference between heels and on flat (L 2.5-inch CS = 0.3 inches, R 2.5-inch CS = 0.7 inches).

Figure 6 Difference between distances reached in CS and in bare feet (CS - flat)



(a)



(b)

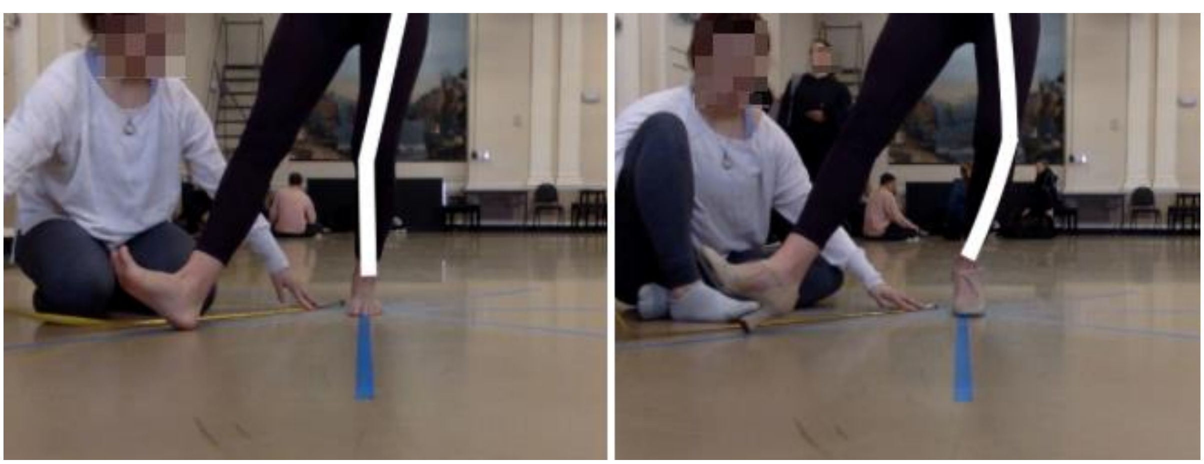
Comparatively, there was more variation on the left foot than the right foot among all subjects, specifically to the medial, posteromedial, posterior, and lateral directions. 3.0- inch CS data to the left consistently exhibited more significant differences in heels vs. barefoot extensions to the anterior, posteromedial, and posterolateral directions (anterior = 3.2 inches, posteromedial = 4.1 inches, posterolateral = 2.1 inches). There was a greater difference between heels and flat to the right in 2.5-inch CS anteriorly and posteromedially, though both heel heights exhibited relatively similar values in comparison with much of the other data points. However, to the right in the posterolateral direction the difference value was -0.7 inches, meaning subjects who wore 2.5-inch CS exhibited more ankle flexibility on flat posterolaterally than with an elevated heel. This value may be considered an outlier, as no other data exhibited such a phenomenon.

In observing the video footage of subjects taking the SEBT test, it is clear that those who wear 2.5-inch CS are more stable in bare feet than subjects who wear 3.0-inch CS. A few subjects who wear 2.5-inch CS exhibited ankle instabilities on the left to the posterior direction in bare feet. Additionally, compensations in the upper body occurred in both 2.5-inch and 3.0-inch CS subjects on flat to the posterior directions, as well as anterolaterally and laterally. There was a trend of instability on the left to the anterior direction in bare feet for 3.0-inch CS subjects.

Video footage also showcases a dramatic increase in unstable behavior while completing the SEBT in CS, particularly for those with a 3.0-inch heel height. With the 2.5-inch CS, subjects had an overwhelming amount of small instabilities when extending their free legs anteriorly and posteriorly. Additionally, subjects completing the test in 2.5-inch CS were unsteady on the left in the posteromedial and posterolateral directions. Both the right and left supporting ankles in 3.0-inch CS were extremely unstable when extending to the anterior and posterior directions, as well as posterolaterally. The most notable difference between the SEBT test in 2.5-inch CS and 3.0-inch CS was that with the higher heel height subjects' supporting ankles shook and micro-corrected while transitioning from reaches in various directions. The overall impression of wearing 3.0-inch CS was that were was never a moment when the supporting foot was in a completely balanced position, especially in dorsiflexion.

Finally, most subjects completing the SEBT in bare feet exhibited a bent valgus knee on their supporting leg when reaching in all eight directions. This means that with supporting ankle dorsiflexion (*plié),* the knee naturally bent slightly medially (Image 2a). This contrasts with the addition of CS to the SEBT test; most subjects in both 2.5-inch and 3.0-inch CS exhibited a bent, varus supporting leg (Image 2b). Thus, dorsiflexion of the supporting ankle in CS caused knee flexion to extend slightly laterally during this portion of the physical test.

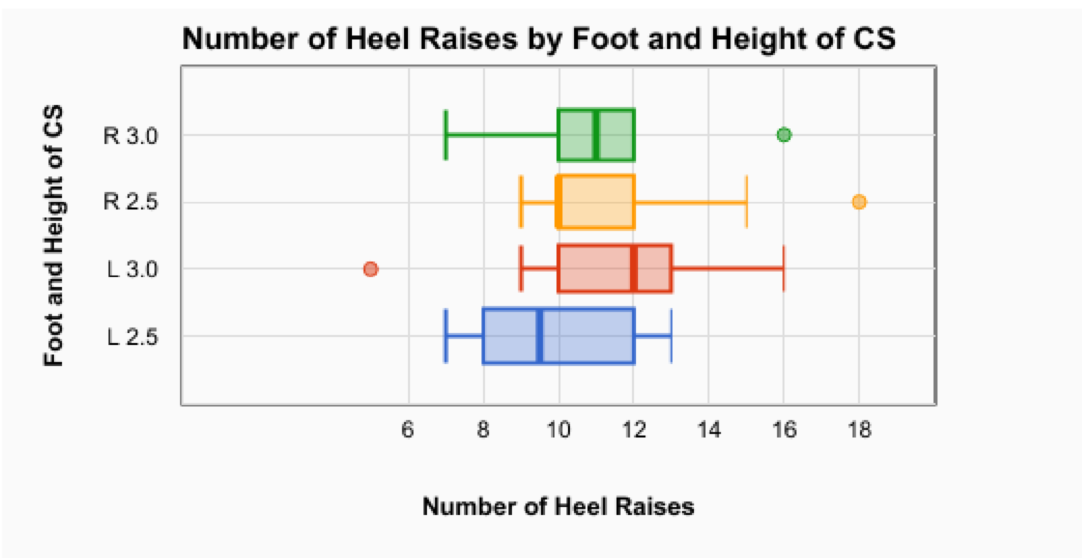
Image 2 Valgus knee orientation on flat (a) versus varus knee orientation upon donning CS (b) during SEBT test



(a) (b)

The results of the heel raise test were quantified in box and whisker plots, sorted by right and left feet and according to subjects who normally wore either 2.5-inch or 3.0-inch CS (Figure 7). Though the subjects were asked to continue to perform the heel raise test and relevé until self-termination, the data points in Figure 12 reflect the numbers at which the co-investigator observed fatiguing effects. Overall, the ranges of the four box plots are relatively long, suggesting that subjects have varying levels of strength and stamina. The two right-foot box plots have similar medians of 10 and 11 heel raises, respectively, as well as similar IQR ranges. The lowest median was 9.5 heel raises for left 2.5 inches, which also had the largest IQR of the four data sets, about 8-12 heel raises.

Figure 7 Box and whisker plots of heel raise test. Each plot represents a data set: green = right 3.0-inch CS, Yellow = right 2.5-inch CS, red = left 3.0-inch CS, blue = left 2.5-inch CS. The ends of the horizontal lines indicate the lowest and highest values within a data set. The box represents the middle 50% of the data and contains the median (vertical line), which is where the most data lies. Any dot shows an outlier, which is not considered in any statistical analysis involving the data sets.



The most inconsistent of the four plots encompasses the left 3.0-inch data. Left 3.0 inch had the highest median of 12 heel raises and the longest upper quartile, but a standard deviation of 3.2 heel raises. Comparatively, the average standard deviation for right 2.5-inch, right 3.0-inch, and left 2.5-inch was 2.5 heel raises. The left 3.0-inch data set also had a low outlier of 5 heel raises before fatigue, contributing to the higher standard deviation. In total, there were three outliers within the data; right 2.5-inch and right 3.0-inch had high outliers of 18 and 16 heel raises, respectively.

Discussion

According to the data collected from the written questionnaire and the heel raise test, 3.0-inch CS do not lead to significantly more injury compared to 2.5-inch CS within the parameters of rehearsals. A similar amount of injuries in the same locations were reported in both heel heights, and the number of successful *relevés* performed during the heel raise test varied across all subjects. However, no subject reached 25 *relevés,* the amount considered normal and healthy for non-dancers. It has been determined that young dancers preparing to study *en pointe* ought to be able to reach 20 heel raises before fatiguing.[17] Though this number is a bit lower than 25, dancers rely much more heavily on their lower-leg musculature than non-dancers and work with a higher range of motion. Thus, they ought to be able to demonstrate significant calf-strength. In one study, pre-professional and professional classical ballet dancers performed an average of 19.7 heel raises, while the control group of non-dancers completed an average of 32.5.[17] Researchers suggested that the Achilles tendons and *triceps surae* of ballet dancers may be weaker as a result of working isometrically *en pointe*, a fully plantar-flexed state involving maximum range of motion. In terms of the data collected within this CS-based study, the median numbers of heel rises on right and left feet was about 10, suggesting that musical theatre dancers experience severely compromised lower-leg functionality as a result of dancing in a partially plantar-flexed state. These findings call for dancers wearing CS to continue strengthening their lower-leg musculature to adequately prepare for dynamic movement.

Though both heel heights create muscular fatigue, the difference values from the SEBT were larger in 3.0-inch CS than 2.5-inch CS. It could be argued that a higher heel height automatically allows subjects in 3.0-inch CS to reach their extended foot further to each direction because of the slightly higher angle of standing foot dorsiflexion. Technically, 3.0-inch CS would allow the wearer to bend, or *plié,* further that someone in 2.5-inch CS, at least until her maximum dorsiflexion was achieved and her heel lifted off the ground (in bare feet, this would be the beginning of a *grande plié*). However, a higher heel height changes the angle of dorsiflexion, not the amount of dorsiflexion itself. What is more, a full *plié* on one foot in an elevated heel is comparable to a single-leg squat, a feat that requires a significant amount of leg strength and stamina. Most choreography does not require dancers to sustain this level of *plié* regularly. As a result, musical theatre dancers often never fully exercise their maximum range of dorsiflexion.

Thus, the noted difference between the distances reached between the two heel heights is likely attributed to varied range of motion of standing ankle joints. On average, subjects wearing 2.5-inch CS reached further in bare feet than subjects in 3.0 inches in the SEBT, suggesting that their ranges of supporting ankle dorsiflexion were greater, while those wearing 3.0-inch CS experienced a decrease in dorsiflexion flexibility. This is most likely a result of the musculature stiffening as a compensation for the extra degrees of freedom created on the anterior and lateral planes with added heel height.

The SEBT test also showed that subjects in 3.0-inch CS exhibited more moments of shakiness, especially while transitioning between directions. These instabilities were notably present to the anterior, posteromedial, and posterolateral directions, which have been established as predicting directions of athletic injury vulnerabilities.[15] Besides these three directions, there was also a high level of physical unsteadiness and variation in distances reached to the lateral direction. The high rate of reported lateral inversion ankle injury may be related to the knee joint shifting laterally with the additional heel elevation. The CoP of the foot moving medially causes the CoM to counter in the lateral direction; compression of the medial forefoot reflects up to the knee joint. The lateral musculature connecting to the knee, such as the lateral head of the gastrocnemius and the peroneus longus, reacts by lengthening further, producing varus knee movement with *plié* (Image 2b).[18] Prolonged forms of stretching promotes energy loss, exposing the lateral sides of the knee and ankle to inversion injury. Because the effects of a varus knee increase as heel height increases, 3.0-inch CS would result in additional lateral instability, explaining the additional variability present during the SEBT test among subjects in the higher CS.

There were also disparities between the distances reached in both heel heights versus on flat, especially on the left. Dancers normally rely heavily on the left foot as the supporting standing leg and/ or the leg the take off from for right-leg jumps, as most dancers and choreographers are right. However, the SEBT was unfamiliar movement to subjects, eliciting extraneous movement in order to balance. Based on this information, it can be deduced that any movement dancers are unaccustomed to performing in CS created further vulnerabilities while in an elevated state.

Subjects performed the physical tests without a prior warm-up, accurately representing how about 65% of the subjects reported beginning rehearsals. Based on the results of this study, there seems to be a relationship between not warming up in CS and decreased stability. A lack of a warm-up and cool-down flanking rehearsal periods most likely adds to the decrease of range of motion that 3.0-inch-wearing subjects especially experience. Concurrently, not warming up or cooling down could worsen the inevitable stiffening of musculature surrounding the ankle joint that the body causes as a supplementary source of stability in reaction to HHS. Cooling down with strengthening and stretching exercises aimed at releasing the lower-leg muscles tightened by rehearsing in CS could counter this phenomenon, benefiting dancers and helping them to avoid potential acute and overuse injuries.

Limitations/ Sources of Bias

The subjects involved in this particular study were all dancers, who can be extremely competitive and habitually self-correct due to the nature of their training. If any problem should occur, such as finding themselves off-balance, dancers will attempt to “fix” and regain their balance instead of terminating the action and starting over. As a result, there is much variability in how subjects interpreted and completed the SEBT, especially in their struggle to keep their lower body stable. They generally accomplished this with extraneous movement of the upper body and extended leg. It was difficult to determine how much of the SEBT test data was actually valid in terms of successful completion. Future studies would benefit from covering more in depth how to properly administer the SEBT test, specifically to dancers.

Something unexpected that occurred within this experiment involved the type of CS that subjects brought to wear during the SEBT. A few subjects regularly wear 2.5-inch boot CS, which lace up to the mid calf, covering more surface area on subjects' legs than regular 2.5-inch CS (Image 3). These boots may have provided additional structural stability on the supporting leg in the SEBT test, causing the 2.5-inch CS wearers to appear stronger overall. It may be beneficial to study the long-term effects of dancing in CS with the additional ankle support provided via the boot structure, and whether or not the musculature becomes overly reliant and unstable without the shoe.

Image 3 2.5 inch CS in boot form that some subjects wore during SEBT test

Future Studies

Transitions and dynamic landings ought to create the most risk for dancers in CS in terms of medial forefoot pressure and lack of RoM in the ankle. Dancers tend to have a higher sense of proprioception due to their dynamic training,[9] but the added degrees of freedom from CS take away from a normal sense of balance. The collected video footage of the SEBT shows that 3.0-inch CS created significant instability while transitioning between steps. These results, grouped with the widely distributed array of individual strength and stamina exhibited from the heels test and the varus knee alignment in plié, calls for additional testing on dynamic takeoffs and landings in CS.

Specifically, future studies ought to explore the pressure changes during dynamic movement in CS, how impact-movement alters the alignment of the knee and ankle, and how the ankle and foot fatigue. While there were no differences in injury rates within this study, the differences in stability and RoM indicate that both heel heights still ought to be compared during data collection.

Finally, a comprehensive warm-up and cool-down program specific for dancing in CS is recommended. Focusing on mobilization and strengthening the flexor hallicus longus, Achilles tendon, *triceps surae,* the peroneus longus, quadriceps, and hips would aid dancers in adequately preparing for dynamic movement, especially in the directions made vulnerable with added heel height (anterior, posteromedial, posterolateral, lateral). Based on the findings of this study, the standardization of a “CS warm-up” may benefit both pre-professional and professional dancers in their training for the professional musical theatre industry, thereby increasing the longevity of their careers.

References

1. Foster R. The ballet class. *Ballet Pedagogy.* Gainesville, FL: University Press of Florida; 2010.

2. Charleston PM, Wilmerding V, Wagler GI, Silby C, Callahan LR, Micheli LJ. Development and health. *The Healthy Dancer: ABT Guidelines for Dancer Health.* New York, NY: Ballet Theatre Incorporated; 2008: 61-62.

3. Cates A. Jobs and markets. *The Business of Show: A Guide to the Entertainment Business for Performing Artists.* Charleston, NC: CreateSpace Independent Publishing Platform; 2014: 28-32.

4. Gu Y, Rong M, Ruan G. The outsole pressure distribution character during high-heeled walking. *Procedia Environmental Sciences*. 2011; 8: 464-468.

5. Gu Y, Ren X, Li J, Rong M. Plantar pressure distribution during high-heeled Latin dancing. *International Journal of Experimental and Computational Biomechanics.* 2010; 1(3): 296-305.

6. Gefen A, Mgido-Ravid M, Itzchak Y, Arcan M. Analysis of muscular fatigue and foot stability during high-heeled gait. *Gait and Posture.* 2001; 15: 56-63.

7. Cowley E, Chockalingam N. The effect of heel height on gait and posture a review of the literature. *Journal of the American Podiatric Medical Association.* 2009; 99(6): 512-518.

8. Ahonen L. Biomechanics of the foot in dance: a literature review. *Journal of Dance Medicine and Science.* 2008; 12(3): 99-108.

9. Ebbeling C J, Hamill J, Crussemeyer J A. Lower extremity mechanics and

energy cost of walking in high-heeled shoes. *Journal of Orthopedic & Sports Physical Therapy*. 94; 19(4): 190-196.

10. Alkjaer T, Raffalt P, Petersen NC, Simonsen EB Movement behavior of high-heeled walking: how does the nervous system control the ankle joint during an unstable walking condition. *PLOS One.* 2012; 7(5): e37390.

11. Li C, Sun D, Li Y, Chang L, Lian W. Energy consumption character due to different forward position change during jogging movement. *International Journal of Biomedical Engineering and Technology*. 2016; 22(2): 137-143.

12. Evans RW, Evans RI, Carvajal S, Peny S. Survey of injuries among West End performers. *Occupational Environmental Medicine*. 1998; 55(9): 585-593.

13. Miller R, Gaul L. Curriculum of bachelor of fine arts commercial dance major. Presented at: Pace University; New York, NY. 2014.

14. Gribble P A, Hertel J, Plisky P. Using the Star Excursion Balance Test to Assess Dynamic Postural-Control Deficits and Outcomes in Lower Extremity Injury: A Literature and Systematic Review. *Journal of Athletic Training.* 2012; 47(3): 339–357.

15. Plisky P J et al. The reliability of an instrumented device for measuring components of the star excursion balance test. *National American Journal Sports Physical Therapy*. 2009; 4(2): 92-99.

16. Lunsford B R, Perry J. Understanding heel-rise test for ankle plantar flexion: criterion for normal. *Physical Therapy*. 1995; 75(8): 694-698.

17. Richardson M, Liederback M, Sandow E. Functional criteria for assessing pointe-readiness. *Journal of Dance Medicine*

18. Zellers J A, van Ostrand K, Silbernagel KG. Calf endurance and achilles tendon

Structure in classical ballet dancers. *Journal of Dance Medicine and Science.* 2017; 21(2): 64-69

19. Sirois-Leclerc G, Remaud A, Bilodeau M. Dynamic postural control and associated attentional demands in contemporary dancers versus non-dancers. *PLoS One.* 2017; 12(3).

20. Cronin N J. The effect of high heeled shoes on female gait: a review. *Journal of Electromyography and Kinesiology*. 2014; 24(2): 258-263.

Appendix

FACEBOOK POST FOR POTENTIAL SUBJECTS:

Hi everyone! I am conducting a scientific study for my senior thesis, regarding injury rates of female dancers who rehearse for musical theatre numbers.. I am looking for volunteers who would like to be subjects of my study! This would involve an online questionnaire and two physical tests.

REQUIREMENTS of PARTICIPANTS

- 20-22 years old, female
- have worn soft-soled character shoes for at least two years
- have been in a musical theatre-based rehearsal process
-

If you fit these requirements and are interested in being a subject, please direct message me on Facebook or email me at ev96039n@pace.edu for more information. I'm looking for 15-25 subjects. Thank you so much!

Best, Evy Vaughan

REPLY TO INTERESTED SUBJECTS' EMAILS/MESSAGES:

Hi (blank),

Thank you so very much for your interest in participating in my study! As promised, here is some more information:

The purpose of my study is to see if a specific heel height (2.5 or 3 inch) of soft-soled character shoes cause more injuries for female collegiate dancers during rehearsal processes. I hope that this research will help point the dance community towards developing a preventative solution for injuries exacerbated by soft-soled character shoes.

As a subject of this study, you would fill out an online survey distributed via Google Forms. The survey will take about 15 minutes to complete. Additionally, there would be a physical component of two tests that measure your lower leg strength/ balance. The physical test will take about 15 minutes to complete.

If you are still interested in participating, please email me back confirming your interest. Attached you will find the Consent Form to become a subject. Please read it, electronically sign it, and email it back to me by Friday, March 9, 2018. If you have any questions or concerns, do not hesitate to reach out. Again, thank you very much for your interest!

Best,

Evy

SURVEY QUESTIONS

Are you female? (Y/N)

How old are you?

Do you dance in soft-soled character shoes (CS)? (Y/N)
If you answered no, please discontinue this survey.

If yes, have you danced in CS for at least 2 years? (Y/N)
If you answered no, please discontinue this survey.

What is the heel height of the soft-soled character shoes (CS) you normally wear? (2.5 inch/3 inch)

Have you been in any rehearsals for dance pieces/shows that required wearing CS in the last 2 years? (Y/N)
If so, how many? (1,2,3,4,5, 6+)

About how many weeks per year did you dance in rehearsals that required wearing CS?

On average, how many rehearsals per week did you attend that required you to wear CS? (1,2,3,4,5,6+)

About how many minutes on average did you wear CS during a rehearsal?

Did you ever get a lower extremity injury/ injuries during these rehearsals while wearing CS? (Y/N) If yes, what region? (pelvis, thigh, knee, calf, ankle, foot, toes)

Do you warm-up **in CS** before rehearsals? (Y/N)
If so, what do you do in your warm-up? (weight transfers, impact training, mobilization of joints, strengthening, stretching, other)

Do you cool-down after rehearsal? (Y/N)

INVITATION FOR PHYSICAL TEST SCHEDULE

Hello!

Thank you for filling out the questionnaire! The second part of my thesis research is comprised of a physical test. Each subject will take two tests in about 5-10 minutes. Below, you will find a google sheet with times in the next couple of weeks to take these tests.

Your subject identification number is:
Please put your identification number next to the slot time that you would like.

Location: 140 Williams Street, 4th Floor (unless informed otherwise).

https://docs.google.com/spreadsheets/d/1BSIIWt_EeeTBhz7ywLSE4ih10YQOTsx_qUxYdIY6bTI/edit?usp=sharing

Thank you very much! If you have any questions, please do not hesitate to contact me.

Best,
Evy Vaughan