EVALUATION OF IMPACT OF POINTE SHOES WEARING ON BALLERINAS' FOOT COMFORT

A Thesis

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by

Qinwen Xu

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ABSTRACT

This study investigated the impact of pointe shoes wearing on ballerinas' foot shapes and comfort. The first and fifth toe angles, plantarflexion angle in demi-pointe position as well as plantar contact pressure (PCP) and center of force (COF) excursions were analyzed in four conditions (standing/walking in running shoes/high heels) through a series of human performance tests with 15 ballerinas and 15 amateur dancers (control group). Interviews were conducted and comfort perceptions were analyzed. The result found the plantarflexion angle in demi-pointe position significantly different between the two groups, and depended on ballerinas' pointe experience. Significant region*group interaction and shoe*group interaction were found in log peak PCP in standing and walking, respectively. A significant shoe*group interaction was found in normalized A-P excursion in walking. The comfort perception in pointe shoes was depended on pointe experience. Ballerinas may have better balance in high heels, however, they could be insensitive to foot pain.

BIOGRAPHICAL SKETCH

Qinwen Xu was born in Jiangsu Province, China, and grew up in Hangzhou, which is the capital city of Zhejiang Province, China. She went to boarding schools from elementary school to high school, and then entered Zhejiang Sci-Tech University to study fashion design and engineering. After graduation, she started a new by setting off to America to pursue her master degree in fiber science and apparel design in Cornell University in the year of 2014.

As a graduate student in Cornell, Qinwen worked closely with her advisor, Dr. Huiju Park. In addition to her studies, she worked as a research assistant with Dr. Park in the summer of 2015 on a project that aimed to improve firefighter's comfort and mobility in fire gears. In the fall semester of the same year, she worked as a research assistant again on an energy-saving garment development project that was sponsored by the United States Department of Energy (DOE). With the help of her advisor and minor committee members, she conducted her research and completed her master thesis in the summer of 2016.

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LIST OF ABBREVIATIONS

PCP	Plantar Contact Pressure
COF	Center of Force
A-P	Anterior-Posterior
L-R	Left-Right
R/S	Standing in Running Shoes
R/W	Walking in Running Shoes
H/S	Standing in High Heels
H/W	Walking in High Heels

Chapter 1 Introduction

Ballerinas are known to have various foot problems from wearing pointe shoes and the practice of techniques that place a large amount of stress on the foot (Grieg, V., 1994; Barringer, J., & Schlesinger, S., 2004). Skin trauma, such as blisters, corns, bruised nails, or even missing nails appear commonly on ballerinas (John, E., 2006). There are also some other common foot ailments among ballerinas including stress fractures, plantar fasciitis, bunions, Achilles tendonitis and many others (Hayes, 2010). Such issues are also common for those who prefer high heels over flat shoes in their daily lives.

Since most dancers are trained starting from classical ballet, knowledge of the basic ballet dancing positions as well as ballet techniques can become of good help in understanding most dance injuries (Motta-Valencia, 2006). To elaborate on the profession of ballerina, the word “ballet” means “to dance, to jump about” (Anderson, 1992), which is quite felicitous since ballet dancing requires a lot of movements like jumping and leaping. There are several different ballet styles including Classical ballet, Neoclassical ballet, Romantic ballet, and Contemporary ballet. Even classical ballet, which originated from traditional ballet vocabulary and dance techniques, has different styles. Some styles are linked with the areas of origin; for example, French ballet is obviously related to its origin place, France. Other classical ballet styles are named after their creators and associated with specific training methods (Grant, 2012).

Extensive research has been conducted on the common injuries among ballerinas as well as the relationship between ballet techniques and the common injuries. Ballet often requires dancers to form unnatural positions, increasing the risk of injuries throughout the whole body. Moreover, because of the repetitive and challenging landings from jumps, ballerinas are prone to bone fractures. An incorrect landing can also cause shin splints (the muscle separates from the bone). Pointe work is highly demanding and arduous on the dancer's ankles, which can easily lead to tendonitis and cause the ankles to weaken (Koutedakis & Jamurtas, 2004). Moreover, the age of ballerinas is also frequently discussed by the scholars.

Being an important role in ballet dancing, pointe shoes were created from the desire to have dancers appear free and weightless while dancing. A proper "en pointe" stance is established when a dancer "gets over" onto the platform of the ballet pointe shoe, which is dependent on a combination of her strength and flexibility as well as the support structure of her ballet pointe shoes (Suffolk, 2012). Pointe shoes serve to create a beautiful image of ballerinas dancing on their tiptoes through its small size and hard materials in the front of the shoe (John, 2006). Despite the pleasing aesthetics on the dance floor, blisters, bunions, and corns are the inevitable result of ballerinas force-fitting their feet into pointe shoes. With the pain of compressing their feet into pointe shoes, ballerinas are likely to choose to wear more comfortable footwear, like a pair of running shoes, for daily use. Nevertheless, not everyone is willing to trade style for comfort. Playing an important role in the world of fashion, high heels are considered must-have shoes for most women. The American Podiatric Medical Association (APMA) has done surveys about high heels wearing on 1,000 US adults. It shows that almost half (49%) of the women participating in the survey would wear high heels, despite the fact that the majority of high heels users (71%) were complaining at the same time that these shoes were hurting their feet (Brielle, 2014). Research has also found that wearing high heels can help increase women's attractiveness (Guéguen, 2014). Although high heels tend to make women look fashionable and maybe more attractive, various physical problems can be caused by wearing high heels, such as blisters, corns, calluses, and pain in different regions including the ball of the foot, heel, and arches of the feet. Through online search (including online forums such as *YAHOO! ANSWERS* and *BALLET Talk for Dancers,* etc.) and personal interviews with three ballerinas from the researcher's personal connection, it has been discovered that ballerinas can have very different opinions towards high heels. Some believe that it may help to "work" their feet, while others believe that it can damage their feet. Yet no studies have been done on the biomechanical performance of ballerinas wearing high heels. However, little literature on the impact of pointe shoes wearing in ballerinas' daily lives has been found.

1.1 Purpose of the Study

Based on the research gap, studies on the impact of pointe shoes wearing on ballerinas' foot shapes, and their daily activities are in need. This study aims 1) to investigate the impact of pointe shoes wearing on ballerinas' foot shapes, and 2) to investigate the extent of how it can affect the comfort perception and biomechanical performance in both running shoes and high heels. Furthermore, ballerinas' comfort perceptions in pointe shoes is also of interest. An understanding of impact of pointe shoes on ballerinas' daily walking may provide practical implications and insights for ballet educators, pointe users and ballet product developers. Given the popularity of high heels in women, it is predictable that ballerinas would wear them in their daily lives as well. Investigating the combined implications of practicing pointe work with long-term use of high heels could provide insights for technologies in forefoot support and prevention of common ballet-related injuries such as metatarsal stress fractures (O'Malley et al., 1996). Thus, investigation on ballerinas' comfort perceptions and biomechanical performance in high heels are included in the research. This research can help clarify the extent to which wearing high heels can aggravate foot problems in dancers. In addition, the study includes interview questions on injuries and pain perception, which can serve as a reinforcement of previous studies.

1.2 Objectives

This study consists of the following main research objectives;

1. To investigate differences between ballerinas and amateur dancers in the first toe angle, the fifth toe angle, and the foot flexion in demi-pointe position.

2. To examine differences between ballerinas and amateur dancers in terms of plantar contact pressure and center of force excursions in standing and walking in running shoes and high heels.
3. To identify the pain regions and comfort perceptions of the participants whiling standing and walking in their running shoes, high heels, and pointe shoes (only for ballerinas' group).
4. To find out, in the ballerinas' group, the correlation between ballet experience and the variables that are significantly different from control group.

Chapter 2 Literature Review

2.1 Studies on Ballet Techniques

The practice of intensive ballet techniques, along with the wear of pointe shoes, is the main cause of most foot deformities and injuries in ballet dancers (Grieg, V., 1994; Barringer, J., & Schlesinger, S., 2004). Among all the dance forms in the world, ballet is probably one of the dance forms that require the most rigorous techniques. Ballet technique is the basic foundation of body movement and different forms commonly seen in ballet (Grant, 2012). It is a crucial facet of ballet performance for the reason that movement execution and dancing method is the core of ballet dancing (Kirstein, Stuart, Dyer & Balanchine, 1952). Great force is placed on the dancers' feet when they are doing repetitive and unnatural motions and movements. The core techniques of ballet, such as alignment, turnout of the legs and pointe work, are common around the whole world. However, there are a few minor variations existing among different ballet styles. Among all the ballet techniques, a distinctive feature is turnout, which refers to an outward rotation of the legs. The technique causes the knee and foot turn outwards. During the rotation, larger extension of the leg takes place (Grieg, 1994). This movement is one of the most important ballet techniques and the basis for all other techniques. Turnout is measured between the feet when the heels are touching together, the measuring unit is in degrees, in which the greatest turnout angle is 180° (Kirstein, Stuart, Dyer & Balanchine, 1952). Alignment in ballet terms means that putting the head, shoulders, and hips on a vertical line. There is another commonly used term, neutral alignment, it can be specified as the balance of the pelvis on the top of the femurs (Laws, Sugano & Swope, 2002). The proper alignment is considered highly important in the ballet dancing society. A good alignment can build an aesthetically fine line and a figure and form that are desired by the field of ballet dance (Decker, 2007). Pointe technique is an important part of classical ballet. To execute this technique, dancers need to perform and bear the whole body weight on the tips of their toes (Barringer & Schlesinger, 2004). It takes extensive practice for one to develop enough strength to perform pointe work. "En pointe" is a ballet terminology that means "on the tip", which refers the pointe work. Other ballet techniques such as toe pointing, or pulling shoulders up and down, can be used to develop a better turnout or alignment. These techniques in a way improve the turns quality in performance, on the other hand they also increase the risk of injuries. Dancing "en pointe" might also lead to prevalence to certain injuries. In a study conducted by Steinberg et al. (2013), none of the 12 dancers who have practiced the "en pointe" position for less than an hour a week had back injuries, while 18 of 69 dancers who have practiced pointe work for over an hour a week did.

The positioning of the feet in ballet is an essential and fundamental part in ballet technique. There are five basic positions in ballet, which are named numerically as first ballet position, second ballet position, third ballet position, fourth ballet position and fifth ballet position, respectively. The five basic positions are all performed with turnout, and have determined the standard placements of feet on the floor. In order to better understand ballet dance. it is important to understand the five fundamental positions. Hence, the plantar pressure in these five positions was tested in this study in ballerina participants.

Figure 2-1. Five Ballet Positions.

Reprinted from Ballet Positions, In *Ballet-Pointe.com*, n.d., Retrieved April 28, 2016, from http://www.ballet-pointe.com/Ballet-positions-ballet-terms.html.

2.2 Studies on Pointe Shoes

Up to date, the design of the pointe shoes has not changed much since its early development. The majority of pointe shoes are still handmade. In fact, the fitting of pointe shoes requires such an expert that making these shoes remains a highly skilled art. As a result, although shoes vary a lot in stiffness or in strength aspect, the dancers will usually not choose their pointe shoes based on the shoe characteristics. They would rather select their shoes based on the one and only aspect, comfort (Cunningham, DiStefano, Kirjanov, Levine & Schon, 1998). The lifetime of the pointe shoes is not long, especially for professional dancers. Once the glue bonds break, the shoes cannot be used anymore. Often, principal dancers will break one or more pair of shoes in one performance alone. Pointe shoes are made using multiple layers of strong glue to reinforce the shoe construction, so that the dancer's weight can be distributed more evenly throughout the whole foot, in a way to lower the load on the toes, enabling the dancer to completely stand on their toes. Nowadays, the main body of a pair of pointe shoes consist of a layer of outer material, a shank, a toe box and an insole with elastic or ribbons to help hold on to the foot and ankle (Shah, 2009). The toe box is rigid and usually made from layers of glue, and fabric, the stiffness of the front of the toe box forms a platform, which supports all the body weight of a dancer when one is going on pointe. The upper part of the toe box is called the vamp. The shank is usually narrow and made of leather, it is attached to the back of the insole and serves as a supporting backbone. Dancers will sew their own ribbons onto the pointe shoes. The elastic needs to be wrapped tightly over the ankle joint (Barringer, 2004). Ballerinas need to "break in" the new and stiff pointe shoes, which means to soften the shoes, when first wearing them. Various methods are employed to break in pointe shoes, depending on the dancer's preference as well as the stiff and hardness of the box (Michael, 2012).

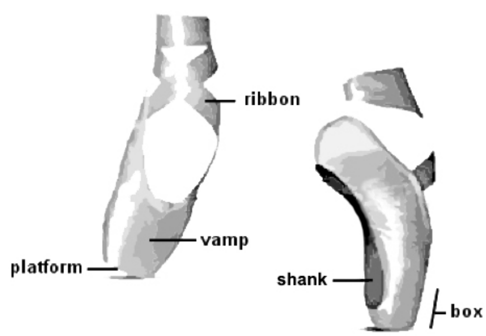

Figure 2-2. Pointe Shoes Structure.

Adapted from Pointe Shoe, In *Wikipedia*, n.d., Retrieved April 28, 2016, from https://en.wikipedia.org/wiki/Pointe_shoe

In order to relieve the pain, ballerinas have their own ways to reconstruct the pointe shoes by adding paddings. Some will use tapes to wrap their feet; some will put lamb's wool, or other suitable cloth into their pointe shoes. Commercialized padding products for pointe shoes can be found in online and local dance supply stores, too. Moreover, there are dancers who will cover their feet in glue or even use other chemicals to make the feet stick. For more extreme and dangerous example, some dancers have even attacked their feet with scissors and blades (John, 2006).

To understand the ergonomics and the design of a pair of pointe shoe, studies have been conducted. Informal tests of the prototype pointe shoe conducted by Colucci and Klein (2008) with the pointe shoes featured with maximized rigidity in platform and the box and proper flexibility in the arch, revealed enthusiasm for certain improvements, such as the boot shoe design and memory foam lining. Pearson and Whitaker (2012) surveyed 65 adolescent female dance students to and tested foot pressure on plantar pressure platforms of the eight female dancers. The study revealed that soft shoes exerted the smallest plantar pressure while pointe shoes exerted the largest pressure on the feet, which place the highest physical demand on a ballerina's feet.

2.3 Age of Ballerinas

Most injuries do not come to a ballerina's realization until later in her life, after years and years of reoccurring strain (Jonas, 1998). Typically, for those who want their ballet dancing lead to a professional field, ballerinas will begin their training between the ages of three and four, the number is six and seven for male ballet dancers. In fact, females are usually considered to have more disadvantages than male in terms of ballet beginning age. While a male ballerina can start ballet training in his late teens, it is highly unlikely to happen in a ballerina. Due to the immaturity of the bones in the feet, prior to the age of eleven or twelve approximately, ballet students' feet are often too soft for pointe work. Serious or even permanent foot injuries could happen if one starts to dance "en pointe" too early. To avoid that, ballet students usually begin to dance "en pointe" after the age of eleven (Weiss, Rist & Grossman, 2009). However, Koutedakis and Jamurtas (2004) have pointed out that many ballerinas actually start to dance on pointe on the average age of six to eight, despite the fact that they are prone to injury at a young age by putting a lot of strain and stress on the body constantly and thus increase risk of injury. In addition, according to a personal interview with a ballerina, it is quite common for ballerinas to start dancing on pointe at an early age before eleven (N. E. Allen, personal communication, February 22, 2015).

2.4 Biomechanics and Injuries in Ballet

Literature review shows that injuries regarding ballet dancing have been widely studied. As a highly demanding dance style, injuries are rather common among ballet performers. Ekegren, Quested, and Brodrick (2014) recorded injury incidences of 266 pre-professional ballet students over one school year. Based on their study, every dancer had 1.42 injuries on average throughout one year and the risk of injury was as high as

76%. Askling, Lund, Saartok, and Thorstensson (2001) surveyed 98 student-dancers studying at the Ballet Academy of Stockholm on injuries of the hamstring. The questionnaire revealed insights about rear thigh injury causes in the context of dancing that 34% of dancers had acute injuries and 17% had overuse injuries in the past 10 years. Moreover, as much as 88% dancers have stated that the acute injuries occurred when they were doing non-intense activities in flexibility training, such as splits. 70% of the dancers who were acutely injured have reported that they have continuing problems. It is also worth mentioning that 88%, which is a lot more than a half, of dancers with acute injuries did not receive, or even seek for appropriate medical treatment.

In addition to such high injury rate, ballerinas suffer from injuries of various kinds as well, such as Achilles tendonitis, bunions, stress fractures and so on, not to mention blisters or other skin problems. In Stretanski and Weber's (2002) secondary study, they discovered a high incidence rate on tendonopathy in ballet, including flexor hallucis longus (FHL) tendonitis or tendinosis, which are almost exclusive in classical ballet. A retrospective review by O'Malley, Hamilton, Munyak, and DeFranco (1996) focused on 51 professional dancers and their stress fracture history and revealed that the most common stress fractures in ballerinas occurred at the 2nd metatarsophalangeal. Moreover, the average recovery duration before returning to performance was 6.2 weeks following diagnosis with only eight refractures occurring an average of 4.3 years, suggesting that the healing time was adequate for most of the surveyed ballerinas. The study also reveals that most of the fractures took an an "insidious onset of pain" that could be due to chronic overuse, while only 15% of the patients have recalled having acute pain. This further supports that idea that many ballet-related injuries are catalyzed by chronic factors such as overuse, incorrect technique, or a lack of plantar support in footwear. Based on an early study, the most common trauma in ballerinas is forefoot supination. In addition to that, ankle and foot are also prone to supination, being the most frequently injured body parts in ballet, which can lead to acute injuries, such as fractures, ligament ruptures or even a distortion. On top of these major traumas, repetitive micro-traumas also occur in ballet dance (Ambré & Nilsson, 1978).

Injuries in different regions of body has also been widely investigated. In the same study of Ekegren, Quested, and Brodrick (2014), they discovered that the most commonly injured body region and structures are the ankle and joints, respectively. The upper body of a ballerina is also easy to get injured due to the choreography or the dance training, which will require them to contort their backs and hips constantly. Often bending the back causes the spine to become prone to certain injuries, such as spasms and pinched nerves. Dancers' hips can become very vulnerable to injuries as well when they splitting their legs in the air during turnout. Such injuries include fractures, strains and bone density loss (Redding et al., 2009). Stretanski and Weber (2002) pointed out that in ballet dance severe injuries could occur in any body region of a dancer, whereas overuse injuries in the lower extremities are the most prevalent. This is the same as in any other styles of dance. Among all the lower limb regions, foot and ankle are the two most frequently injured areas among dancers, with significantly higher rates reported in ballerinas (Wanke, Arendt, Mill & Groneberg, 2013; Ambré & Nilsson, 1978). Since the ballet positions is associated with foot movements mostly in an unnatural way, for instance, the sur les pointes (on the tips of the toes) position requires maximal ankle, hindfoot, and midfoot plantar flexion, while placing high forces across those joints (Kadel, 2014). According to Stretanski and Weber, the predominant injuries in foot and ankle region is linked with the anatomic requirements of the five ballet positions with the use of pointe shoes. Although according to a study carried out by Steinberg et al., the most common injured region was knee, taking up 40.4% of all injury areas (Steinberg et al. 2013).

2.5 Biomechanics and Foot Issues while Wearing High Heels

Due to the similarity of foot issues in high heels and in pointe shoes, ballerinas could be increasing their susceptibility to injury in the lower extremities. Torba's and Rice's (1993) study suggests that the concentration of plantar pressure in the forefoot while performing "en pointe" is comparable to that of wearing high heels, where much of the pressure rests in the metatarsals. Thus, rigorous practice of "en pointe", combined with frequent wearing of high heels, could lead to even more onerous and chronic overuse of the forefoot's tiny bones. Findings by Csapo et al. (2010) suggest that high heels can cause a shortening of the Achilles' heel and therefore a reduction in ankle flexibility. Research by Csapo, Maganaris, Seynnes, and Narici (2010) has produced the same result. The study aimed at measuring the impact of chronic high-heel use revealed changes in anatomical structures of the leg: the study investigated 11 women who regularly wore high heels and found a shortening in their Gastrocnemius medialis fascicle length along with stiffening of the Achilles' tendon compared to the control group of 9 women. The anatomical effects described led the women to have reduced range of ankle motion, but no significant differences in functional capabilities were observed.

2.6 Studies on Plantar Pressure

The main apparatus of the study was 3D foot scanner and plantar pressure sensors system. Earlier studies conducted in high heels and pointe shoes conditions have used same or similar methodology in their research. Nyska, McCabe, Linge, and Klenerman (1996) investigated plantar pressure measurements of ten women wearing high heels and low heels through the use of in-shoe pressure measurement systems. Steps were collected for 13 seconds after the participants have walked at a certain speed for more than 5 minutes and displayed balanced walking. Data was then analyzed based on seven different plantar regions. Toes were divided into hallux region and 2 to 5 toes region, fore foot was divided to lateral forefoot, intermediate forefoot and medial forefoot, the left two regions were midfoot and heel regions. The results revealed that high heels moved a portion of the plantar load from the hindfoot to the forefoot. Moreover, much of the load was concentrated on the hallux region and the medial forefoot region. The study seemed to suggest that long-term use of high heels can exacerbate the symptoms of hallux valgus deformities through increased and prolonged load on the medial forefoot. A study by Snow, Williams, and Holmes (1992) of 45 female participants from University of California community measured the differences in plantar pressures between bare-foot and low, medium to high heel conditions. The measured plantar regions were the hallux, the 1st to 5th metatarsals, and the heel. In agreement with Nyska, McCabe, Linge, and Klenerman (1996), this study supports the transition of load from the heel to the forefoot—more specifically, the metatarsal heads—as heel height increases. The study also suggests that toe box shape can affect the distribution of load among the five metatarsals of the foot; specifically, Nyska et al. (1996) suggest that the narrower the toe box, the more evenly distributed the plantar pressures were among all the metatarsals. The implications of this suggestion are that narrow toe-boxed high heels could balance out peak pressure between metatarsals and help prevent overloading.

The foot pressure analysis has also been used in the studies of pointe shoes. Torba and Rice (1993) explore the physical burden of "en pointe" dancing on the lower extremities with the use of pressure sensitive film and force sensing resistors. The study revealed that about 80% of the body's weight lies in the forefoot's bony structure (i.e. the metatarsophalangeals) and the end of the toes with pressures ranging from 0 to 500 kPa. Only 5% of total force was found in the region of heel and the ball of foot, with another 15% of force found being supported by the very shear forces provided by the skin. The very nature of the "en pointe" position is unnatural for the human body, where the pressure builds significantly on the foot region with smaller bones and was obviously not meant to bear total body weight. Certainly, the results suggest that chronic overuse of the “en pointe” position, without the aid of shock-absorption or form-enhancing technologies, could lead to disfiguration and long term damage of the forefoot.

Chapter 3 METHODOLOGY

3.1 Experiment protocol

In order to investigate the foot shapes and biomechanical performance of ballerinas, a series of human performance tests were conducted with Institutional Review Board Approval. There are two groups of participants for this study. The first group includes 15 ballerinas with more than 3 months experience on pointe. The second group, which served as a control group, includes 15 female self-reported amateur dancers (not limited to ballet) with no experience on pointe. Participants of both groups are over 18 and able to walk in high heels for more than half an hour. The control group of female amateur dancers can control the variables that might be different in dancers and in those don’t dance at all (such as weight, height, high heels using preference, etc.) in some extent, so that the difference to be found between the two groups is most possibly caused by the wear of pointe shoes, not just by dancing.

Same high heels of different sizes are purchased for the purpose of this study. The heel height is 3.54" (9 cm). The high heels are commercially available and in the style of a basic pumps.

3.2 Apparatus

The 3D scan image and data of both feet are collected using an INFOOT® 3D foot scanner (I-Ware Laboratory Co., Ltd., Minoh-City, Osaka, Japan) as shown in

Figure 3-1. The participant put their one bare foot inside of the scanner during the scanning.

Figure 3-1. 3D Foot Scanner.

The foot scanning takes 10 seconds for each scan. The foot scanner captured the 3D image of the whole foot, the software then automatically calculated the foot measurements (Figure 3-2).

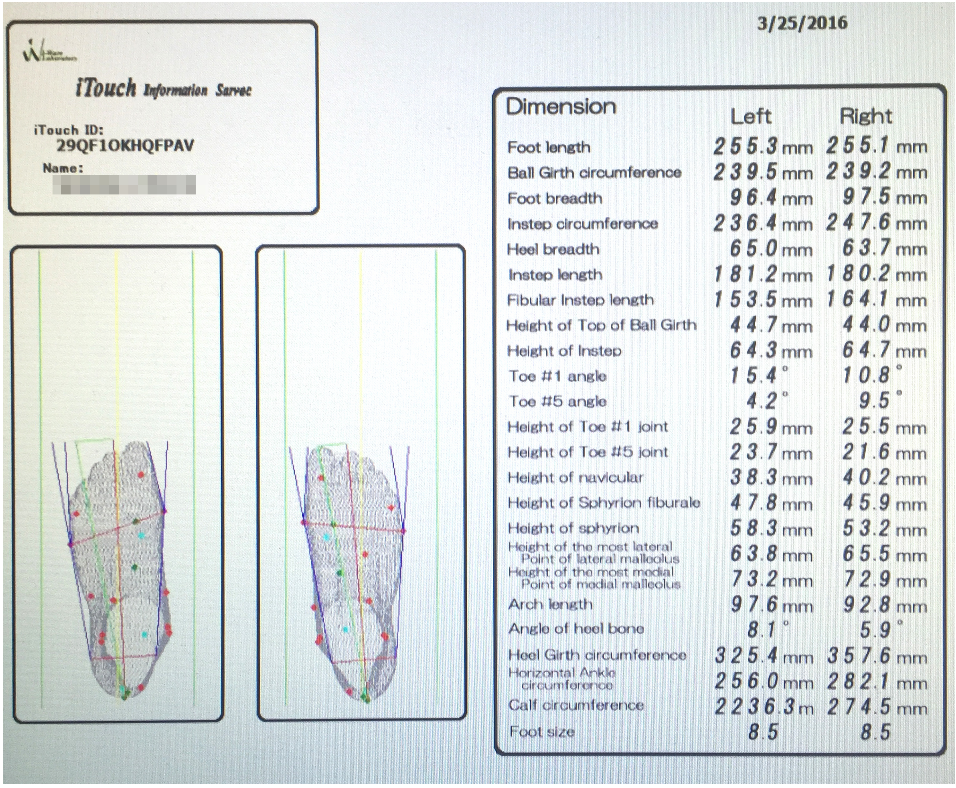

Figure 3-2. Automatically Calculated Foot Measurements.

The plantar pressure data was collected by the F-Scan® (Teskcan Inc., Boston, MA, USA) in-shoe pressure system (see Figure 3-3). The system uses pressure sensors that can be placed inside the shoe to collect timing and pressure data.

Figure 3-3. Participant Walking on the Treadmill with Foot Pressure System.

A recording of 10 seconds was made in each experiment condition. The sensors sampling rate was at 250 Hz. The peak plantar contact pressure of the average stance was collected, which can be used as an indication of foot discomfort. Because at the beginning and the end of walking involve part of standing, in order to only analyze the normal and stable walking of the participants, the first and the last stances were excluded.

Moreover, the center of force (COF) data of the anterior-posterior trajectory and left-right trajectory was collected. The trajectory data was the excursions of the center point of plantar pressure, and was measured automatically by the software (as shown in Figure 3-4, the red lines circled by the ellipses indicate the anterior-posterior trajectory of center of force). COF refers to the point where the force of the body on the plantar foot would be if concentrated on a single point. The trajectory of COF is a measure of the activity of motor system in moving this point (Ruhe, Fejer, & Walker, 2011). The COF reflects the response of the neuromuscular system to correct the center of gravity of the body, especially how the ankle muscles are affected by the unstable shoes, contributing to ankle joint movements and the stability of the ankle joint (Murray, Seireg, & Scholz, 1967; Koozekanani, Stockwell, McGhee, & Firoozmand, 1980; Nigg, Federolf, & Landry, 2010). In most cases in unstable shoes, the body sways more while adjusting and maintaining postural control, resulting in greater COF excursions (Murray, Seireg, & Scholz, 1967).

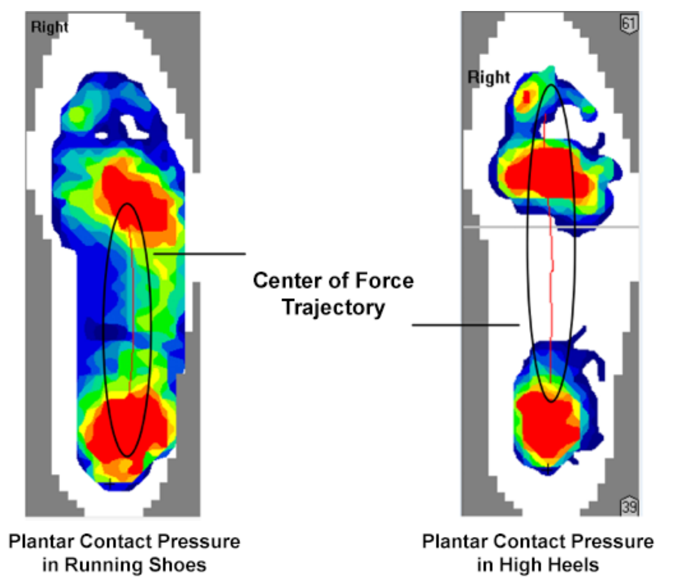

Figure 3-4. Plantar Contact Pressure Image.

3.3 Procedures

3.3.1 3D Foot Scanning

A 3D foot scanning was conducted for the both feet of each participant in both standing and demi-pointe positions. Geo-magic® software (Geomagic Inc., Morrisville, NC, USA) was used to manually calculate the foot flexion angles in demi-pointe position. Due to the invisibility of the foot bones and joints, the angle α was used to indicate the foot joint flexion in this position (Figure 3-5). The first toe angle and the fifth toe angle data was collected from the foot scan of standing position (Figure 3-6).

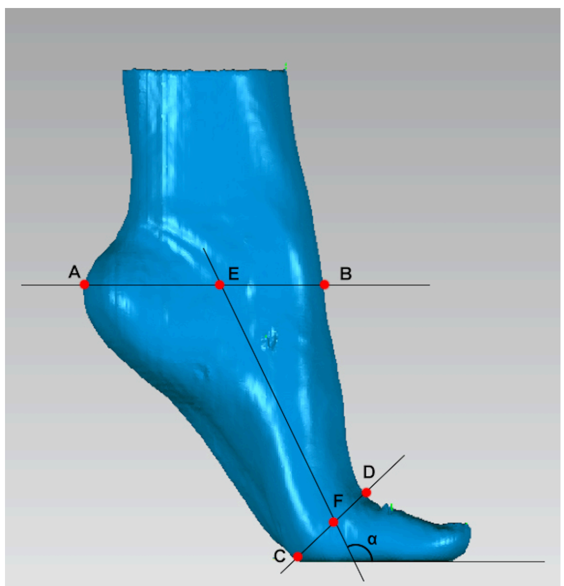

Figure 3-5. 3D Foot Scan Image in Geo-magic® Software.

Note. A is the pternion point of the foot; AB is the horizontal line passing through point A; E is the middle point of line AB; C is the posterior landing point of the foot; D is the closest point to point C on the curve of the surface of the foot; F is the middle point of line CD; α is the angle between line EF and the horizontal line passing through point C.

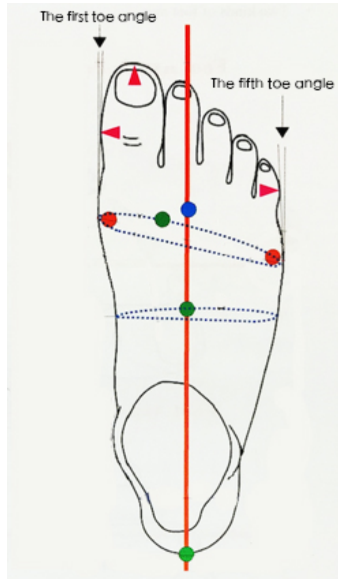

Figure 3-6. Toe Angles in Standing Position.

1) In standing position

In order to get the objective foot measurements of each participants. The participant's both feet were scanned in a standing position. Before the scanning, they were asked to take off their own shoes and socks. The markers, which can help the software to better recognize different foot measurements and for the easy adjustment later on, were attached on the foot that is to be scanned. The participant was asked to put on the black pants made for the foot scanning to avoid any light exposure during scanning. The scan was conducted once for each foot. To find out the impact on the foot shapes due to the wear of the pointe shoes, among all the foot measurements calculated by the software, the researcher recorded the foot length, and investigated the toe #1 angle and toe #5 angle.

2) In a full demi-pointe position

After the normal standing pose scanning, the participant was asked to stand in a full demi-pointe position shown as below. The foot was scanned twice for each foot using 3D foot scanner. Foot flexion in demi-pointe position (Figure 3-5) was also included in data collection. The software Geo-magic® was used to manually calculate the foot flexion angle in demi-pointe position.

3.3.2 Plantar Contact Pressure Data Collection

For plantar contact pressure (PCP) data collection, standing and walking tasks in participants' own running shoes and high heels provided by the researcher were also conducted for both the groups. In addition, for the ballerinas only, five ballet positions were performed in their own pointe shoes in order to capture the pressure information in pointe shoes.

1) Standing/Walking Task

In the standing and walking task, the participants were asked to stand naturally on a treadmill facing the control panel for 5 minutes and then walk on the same treadmill for another 5 minutes in both their own running shoes and in the high heels provided by the researcher. Hence, there were four conditions during the experiment (Condition 1: standing in running shoes (R/S); Condition 2: walking in running shoes (R/W); Condition 3: standing in high heels (H/S); Condition 4: walking in high heels (H/W)). The participants were given enough time to adjust their speed to their preference in the walking task. The speed was recorded. There is a 5 minutes break between each task. Foot planter contact pressure sensors were sticky taped on the shoes. Before every experiment, calibration or recalibration was done. Each experiment was recorded for 10 seconds for 3 times for each task. The 1st recording starts at the beginning of the task, the 2nd one starts after two minutes, the 3rd starts after 4 minutes. After the standing and walking tasks, the comfort perception in each condition was asked, which were indicated by the use of a Likert scale with discomfort level of 0-5.

2) Five ballet positions

This part is for group 1 ballerinas who have more than 3 months experience on pointe only. In this part, the participant performed the five basic ballet positions in their own ballet shoes accordingly with no repetition. Each position was held for 10 seconds. F-scan (Tekscan Inc.) planter contact pressure system was used. Before every experiment, calibration was done.

3.3.3 Personal Interview

The personal interview was conducted with each participant, with the use of a questionnaire (attached in Appendix 1). The interview questions for the control group are the same questionnaire without all the ballet-related questions. The personal interview was conducted during and after the experiment. The conversation was recorded. The questionnaire is printed out before the participant comes and filled out by the researcher during the personal interview.

1) Group 1: Ballerina

There are three parts of interview questions for ballerinas. Firstly, demographic questions such as age, height and weight were asked. Secondly, dancing experience related questions, including ballet style, ballet starting/quitting age, pointe shoes starting/quitting age, practice frequency, paddings/orthotic products using habits, comfort perception in pointe shoes and pain regions in pointe shoes, were also asked. At last, questions about high heels wearing habit, frequency and typical height, along with the pain area in high heels were asked as well.

2) Group 2: Amateur dancers

For the control group, only the demographic questions and high heels related questions were asked. The questions were asked in the same way as the ones for the ballerinas.

3.4 Data analysis

This study recruited 15 ballerinas (age: 19.6 ±1.4, height: 166.02cm ±6.90, weight: 60.06kg ±17.67) as study group participants and 15 female amateur dancers (age: 20.87 ±2.17, height: 163.72cm ±3.63, weight: 58.76kg ±20.08) as control group participants. The foot sizes of ballerina participants range from size 5.5 to 10 (foot length: 247.95cm ±10.10), whereas the foot sizes of control group participants range from size 5.5 to size 9 (foot length: 240.95cm ±10.12). The foot length has a good variability in both groups, which provides more credibility for the results of the study.

Each participant's foot was divided into 5 plantar regions; hallux region, toes region, forefoot region, midfoot region and heel region (see Figure 3-7). The PCP was recorded in each experiment condition. The peak PCP of hallux, forefoot and heel region was collected in averaged stance of each recording, excluded the first and the last stance, and analyzed by mixed models. A log transformation of the pressure was taken in the mixed model while analyzing the foot peak PCP in RS, RW, HS, HW four conditions, no transformation was made for the peak PCP in five ballet positions. The variables that might have an impact on the response were controlled as fixed effect. The participants were asked to walk in their preferred walking speed, which ranges from 0.27~0.94 (m/s) in high heels and 0.31~1.34 (m/s) in running shoes. The speed was smaller than average walking speed. Although the participants were able to walk freely, they might feel the restriction from the pressure system attached to the lower body, which could possibly lead to the slow speed.

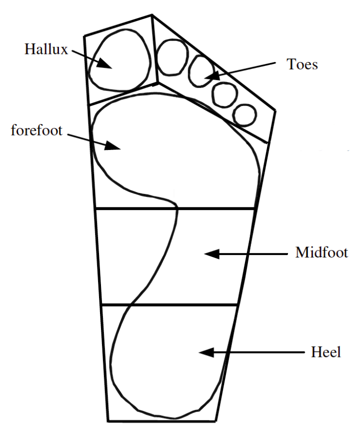

Figure 3-7. Plantar Regions.

During the standing and walking experiment, other than peak PCP data, the COF data was also analyzed using mixed models. The researcher collected the data of anterior-posterior excursion (A-P excursion) and left-right excursion (L-R excursion) of COF during each recording. A mixed model was used to analyze the difference between ballerina group and control group. Height, weight and side were controlled in the model. A-P excursion and L-R excursion were normalized by the foot length. The Normalized data was used in the model.

Comfort perception in pointe shoes was investigated in this study. A Likert scale of 0-5 rating was used, indicating the discomfort/pain level of the ballerinas during pointe dancing. Same Likert scales were used to indicate the discomfort level in the four conditions in the experiment. The participants were also asked to rate the discomfort level in their own high heels. The result shows that the comfort perception in high heels used in this research is similar to the ones of their own, which means that the research can well reflect what they feel in their own high heels wearing.

In order to control the subject effect, the study focused on the comfort perception change from running shoes to high heels. The difference of the Likert scale rating of discomfort level from Condition 1 to Condition 3, and Condition 2 to Condition 4 was taken.

For each response, all the possible effects were controlled in the statistical models, such as height, weight, foot length and side. Holm correction was used for the p-values.

Chapter 4 Results and Discussion

4.1 Foot Measurements

For the foot flexion in demi-pointe position (Table 4-1), it is significantly different for the two groups, where the p-value is 0.009 (0.003 before correction). The ballerina group has a much smaller foot angle in demi-pointe position (Figure 4-1). For the first toe angle and the fifth toe angle, after Holm correction, the p-value are 0.076 and 0.827 (0.038 and 0.827 before correction), respectively. The difference did not reach statistical significance, but based on the box plot, the difference in the first toe angle was close to the significant level (Figure 4-2). Although given the fact that the one ballerina's toes have been compressed in a small toe box for such a long time, some may believe that their big toe will become more inwards, or their toes will become more "box-shaped", according to one of the ballerina participants, the evidence suggests otherwise.

Table 4-1. Results of Group Effect from ANOVA Tables of Foot Measurements

Variable	Group	Mean	SD	95% Confidence Interval		p-value	F value
Foot Flexion Angle in Demi-Pointe Position	1	95.792	6.701	91.879	99.704	**0.009**	10.756
	2	104.650	9.181	100.738	108.563		
Toe #1 Angle	1	12.363	3.946	10.350	14.376	0.076	4.722
	2	9.343	4.574	7.330	11.356		
Toe #5 Angle	1	11.157	5.488	8.728	13.586	0.827	0.049
	2	10.787	4.698	8.358	13.216		

Note. Group 1 stands for ballerina group, 2 stands for control group.

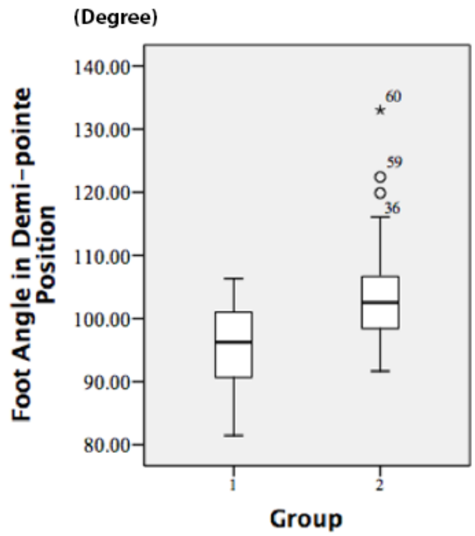

Figure 4-1. Box Plot of Foot Angle in Demi-Pointe Position.

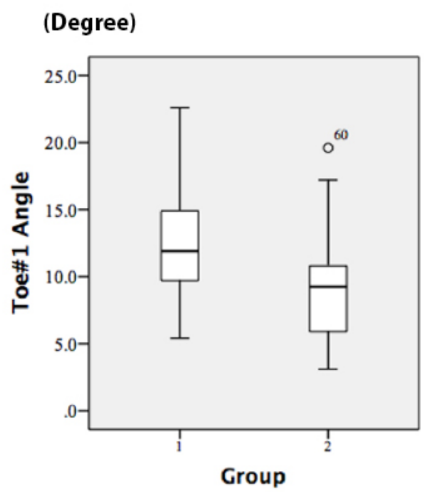

Figure 4-2. Box Plot of Toe #1 Angle.

The correlation between the significant response and the professional experience of the ballerinas was investigated. Since pointe experience and pointe starting age are highly correlated (r =-0.909), ballet experience and ballet starting age are also highly correlated (r =-0.749), only the variables of Ballet Experience and Pointe Experience were included in the mixed model as a fixed effect. The correlation table (Table 4-2) and the scatter plot (Figure 4-3) indicate that the foot flexion angle in demi-pointe position has a strong correlation with pointe experience.

Table 4-2. Correlations of Foot Flexion Angle in Demi-Pointe Position and Ballet-related Experience

Correlations

		Ballet Experience	Pointe Experience	Peak Time Practice Frequency (per month)
Foot Angle in Demi-pointe Position	Pearson Correlation	-.209	-.526**	.146
	Sig. (2-tailed)	.267	.003	.441
	N	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Note. Ballet Experience and Pointe experience are years of ballet dancing and pointe dancing, respectively.

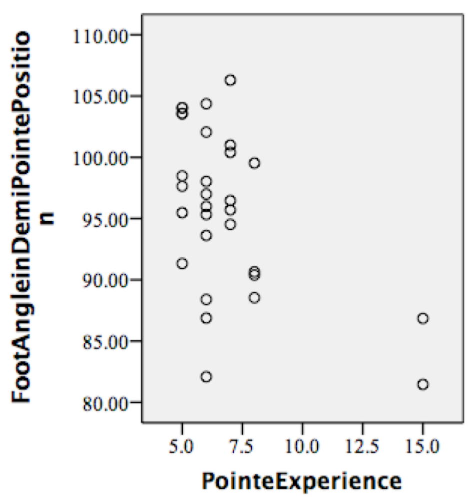

Figure 4-3. Scatter Plot of Foot Angle in Demi-Pointe Position and Pointe Experience.

4.2 Plantar Contact Pressure

No significant difference was found in log peak PCP for group main effect (Table 4-3). However, a significant region*group interaction was discovered in log peak PCP in standing condition; a significant shoe*group interaction was found in log peak PCP in walking condition (Table 4-4).

Table 4-3. Results of Group Effect from ANOVA Tables of Log Peak PCPs

Variable	Group	Mean	SD	95% Confidence Interval		p-value	F value
Log Peak PCP (Standing)	1	1.989	0.260	1.895	2.034	0.383	0.808
	2	2.012	0.277	1.937	2.076		
Log Peak PCP (Walking)	1	2.501	0.248	2.416	2.584	0.440	0.629
	2	2.547	0.234	2.461	2.629		

Table 4-4. Results of Group Interactions from ANOVA Tables of Log Peak PCPs

Estimated Marginal Means

Variable	Group		Mean	SE	95% Confidence Interval		p-value	F value
Log Peak PCP (Standing)	1	Hallux	1.812	0.037	1.736	1.888	**0.018**	4.066
		Forefoot	2..012	0.036	1.938	2.086		
		Heel	2.070	0.036	1.996	2.143		
	2	Hallux	1.793	0.037	1.717	1.869		
		Forefoot	2.070	0.036	1.996	2.144		
		Heel	2.157	0.036	2.082	2.232		
Log Peak PCP (Walking)	1	High heels	2.564	0.041	2.478	2.649	**0.049**	3.907
		Running shoes	2.437	0.041	2.351	2.523		
	2	High heels	2.582	0.041	2.496	2.667		
		Running shoes	2.509	0.041	2.423	2.595		

Based on the pairwise comparisons of region*group interaction in log peak PCP in standing condition (Table 4-5 and Table 4-6), in ballerinas' group, the peak pressure in hallux region is smaller than in forefoot and heel region; the peak pressure in forefoot region has no significant difference than in heel region. However, in the control group, the peak pressure in heel region is larger than in forefoot region; the peak pressure in forefoot region is larger than in hallux region. Figure 4-4 shows the box plot of log peak PCP in standing condition for the two groups.

Table 4-5. Pairwise Comparisons of Region*Group Interaction in Log Peak PCP in Standing for Group Factor

Pairwise Comparisons[a]

region	(I) group	(J) group	Mean Difference (I-J)	Std. Error	df	Sig.[b]	95% Confidence Interval for Difference[b]	
							Lower Bound	Upper Bound
1	1	2	.019	.052	23.213	.721	-.089	.127
	2	1	-.019	.052	23.213	.721	-.127	.089
2	1	2	-.058	.051	20.650	.270	-.164	.048
	2	1	.058	.051	20.650	.270	-.048	.164
3	1	2	-.087	.051	21.139	.103	-.194	.019
	2	1	.087	.051	21.139	.103	-.019	.194

Based on estimated marginal means

a. Dependent Variable: log_peakpcp_s.

b. Adjustment for multiple comparisons: Bonferroni.

Note. Region 1 stands for hallux; region 2 stands for forefoot, region 3 stands for heel.

Table 4-6. Pairwise Comparisons of Region*Group Interaction in Log Peak PCP in Standing for Region Factor

Pairwise Comparisons[a]

group	(I) region	(J) region	Mean Difference (I-J)	Std. Error	df	Sig.[c]	95% Confidence Interval for Difference[c]	
							Lower Bound	Upper Bound
1	1	2	-.201*	.027	575.275	.000	-.265	-.136
		3	-.258*	.027	575.275	.000	-.323	-.193
	2	1	.201*	.027	575.275	.000	.136	.265
		3	-.057	.025	574.746	.069	-.118	.003
	3	1	.258*	.027	575.275	.000	.193	.323
		2	.057	.025	574.746	.069	-.003	.118
2	1	2	-.277*	.027	575.941	.000	-.341	-.213
		3	-.364*	.027	576.968	.000	-.430	-.299
	2	1	.277*	.027	575.941	.000	.213	.341
		3	-.087*	.026	576.521	.002	-.149	-.025
	3	1	.364*	.027	576.968	.000	.299	.430
		2	.087*	.026	576.521	.002	.025	.149

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Dependent Variable: log_peakpcp_s.

c. Adjustment for multiple comparisons: Bonferroni.

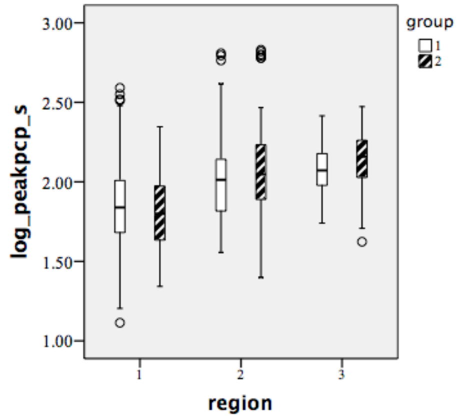

Figure 4-4. Box Plot of Log Peak PCP in Standing.

According to the pairwise comparisons of shoe*group interaction in log peak PCP in walking condition (Table 4-7 and Table 4-8), the increase of peak pressure from running shoes condition to high heels condition is smaller in ballerinas' group than in the control group. Figure 4-5 shows the box plot of log peak PCP in walking condition for the two groups.

Table 4-7. Pairwise Comparisons of Shoe*Group Interaction in Log Peak PCP in Walking for Group Factor

Pairwise Comparisons[a]

shoe	(I) group	(J) group	Mean Difference (I−J)	Std. Error	df	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	1	2	−.018	.058	16.838	.764	−.141	.105
	2	1	.018	.058	16.838	.764	−.105	.141
2	1	2	−.072	.058	16.838	.233	−.195	.051
	2	1	.072	.058	16.838	.233	−.051	.195

Based on estimated marginal means
a. Dependent Variable: log_peakpcp_w.
b. Adjustment for multiple comparisons: Bonferroni.

Note. Shoe 1 stands for high heels; shoe 2 stands for running shoes.

Table 4-8. Pairwise Comparisons of Shoe*Group Interaction in Log Peak PCP in Walking for Shoe Factor

Pairwise Comparisons[a]

group	(I) shoe	(J) shoe	Mean Difference (I−J)	Std. Error	df	Sig.[c]	95% Confidence Interval for Difference[c] Lower Bound	Upper Bound
1	1	2	.127*	.019	614.028	.000	.089	.165
	2	1	−.127*	.019	614.028	.000	−.165	−.089
2	1	2	.073*	.020	614.028	.000	.034	.111
	2	1	−.073*	.020	614.028	.000	−.111	−.034

Based on estimated marginal means
*. The mean difference is significant at the .05 level.
a. Dependent Variable: log_peakpcp_w.
c. Adjustment for multiple comparisons: Bonferroni.

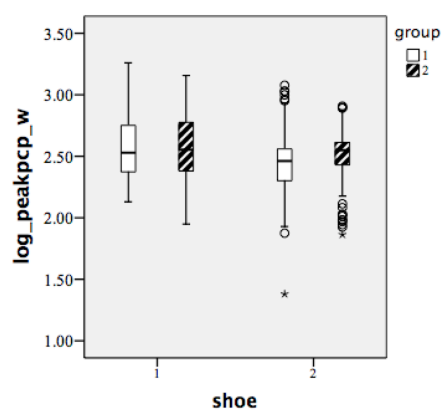

Figure 4-5. Box Plot of Log Peak PCP in Walking.

In five ballet positions, no significant difference was found between different positions (Table 4-9). The significant side main effect was caused by different foot positioning in five ballet positions. Different regions have significantly different peak PCP, according to the pairwise comparisons table (Table 4-10), ballerinas tend to put most of their weight in heel region.

Table 4-9. ANOVA Table of Peak PCP in Five Ballet Positions

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	13.000	.247	.627
side	1	428	4.217	.041
state	4	428	.195	.941
region	2	428	137.866	.000
weight	1	13.000	1.976	.183

a. Dependent Variable: peakPCP.

Note. State indicates different ballet positions.

Table 4-10. Pairwise Comparisons of Region Effect in Peak PCP in Five Ballet Positions

Pairwise Comparisons[a]

(I) region	(J) region	Mean Difference (I–J)	Std. Error	df	Sig.[c]	95% Confidence Interval for Difference[c]	
						Lower Bound	Upper Bound
1	2	-95.427*	20.406	428	.000	-135.535	-55.318
	3	-329.287*	20.406	428	.000	-369.395	-289.178
2	1	95.427*	20.406	428	.000	55.318	135.535
	3	-233.860*	20.406	428	.000	-273.969	-193.751
3	1	329.287*	20.406	428	.000	289.178	369.395
	2	233.860*	20.406	428	.000	193.751	273.969

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Dependent Variable: peakPCP.

c. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

4.3 Center of Force Data

For COF trajectory, no significant difference for group main effect was found in either normalized A-P excursions or normalized L-R excursions (Table 4-11). A significant shoe*group interaction was found in normalized A-P excursion in walking condition (Table 4-12).

Table 4-11. Results of Group Effect from ANOVA Tables of COF Excursions

Variable	Group	Mean	SD	95% Confidence Interval		p-value	F value
Normalized L-R Excursion (Standing)	1	0.00074	0.00057	0.00063	0.00085	0.778	0.080
	2	0.00088	0.00129	0.00063	0.00112		
Normalized A-P Excursion (Standing)	1	0.00555	0.00347	0.00489	0.00621	0.340	0.976
	2	0.00755	0.00881	0.00587	0.00923		
Normalized L-R Excursion (Walking)	1	0.00917	0.00268	0.00866	0.00968	0.212	1.705
	2	0.00816	0.00269	0.00736	0.00869		
Normalized A-P Excursion (Walking)	1	0.06124	0.00989	0.59360	0.63134	0.247	1.452
	2	0.05830	0.11251	0.05609	0.06051		

Table 4-12. Results of Group Interactions from ANOVA Tables of COF Excursions

Estimated Marginal Means

Variable	Group		Mean	SE	95% Confidence Interval		p-value	F value
Normalized A-P Excursion (Walking)	1	High heels	0.057	0.003	0.052	0.062	**0.020**	5.545
		Running shoes	0.067	0.003	0.062	0.072		
	2	High heels	0.055	0.003	0.050	0.060		
		Running shoes	0.061	0.003	0.055	0.066		

The pairwise comparisons of shoe*group interaction in normalized A-P excursion in walking condition (Table 4-13 and Table 4-14) found that, the decrease of A-P excursion difference from running shoes condition to high heels condition is larger in ballerinas' group than in the control group. Figure 4-6 shows the box plot of A-P excursion in walking condition for the two groups.

Table 4-13. Pairwise Comparisons of Shoe*Group Interaction in Normalized A-P Excursion in Walking for Group Factor

Pairwise Comparisons[a]

shoe	(I) group	(J) group	Mean Difference (I−J)	Std. Error	df	Sig.[b]	95% Confidence Interval for Difference[b]	
							Lower Bound	Upper Bound
1	1	2	.001	.004	18.240	.875	−.007	.008
	2	1	−.001	.004	18.240	.875	−.008	.007
2	1	2	.005	.004	18.551	.182	−.003	.013
	2	1	−.005	.004	18.551	.182	−.013	.003

Based on estimated marginal means

a. Dependent Variable: NormalizedAP_w.

b. Adjustment for multiple comparisons: Bonferroni.

Table 4-14. Pairwise Comparisons of Shoe*Group Interaction in Normalized A-P Excursion in Walking for Shoe Factor

Pairwise Comparisons[a]

group	(I) shoe	(J) shoe	Mean Difference (I−J)	Std. Error	df	Sig.[c]	95% Confidence Interval for Difference[c]	
							Lower Bound	Upper Bound
1	1	2	−.010*	.001	189.939	.000	−.013	−.008
	2	1	.010*	.001	189.939	.000	.008	.013
2	1	2	−.006*	.001	189.992	.000	−.008	−.003
	2	1	.006*	.001	189.992	.000	.003	.008

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Dependent Variable: NormalizedAP_w.

c. Adjustment for multiple comparisons: Bonferroni.

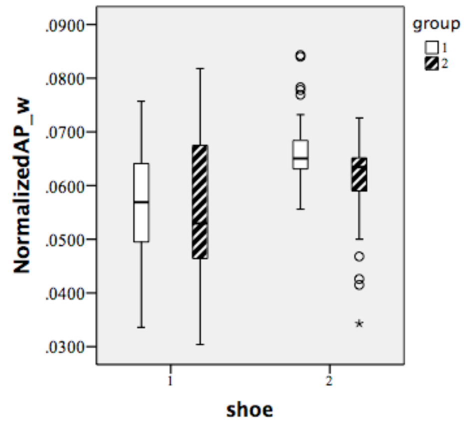

Figure 4-6. Box Plot of Normalized A-P Excursion in Walking.

4.4 Pain Regions and Comfort Perception

The pointe dancing results in problems in many regions, the percentage of each region was shown in Figure 4-7. Although the ballerinas have injuries almost all over the body, during the interviews with the ballerinas, four of them confessed that even the therapist suggested them to rest for a longer time or even never dance again, they have chosen to ignore the pain and get back to the training.

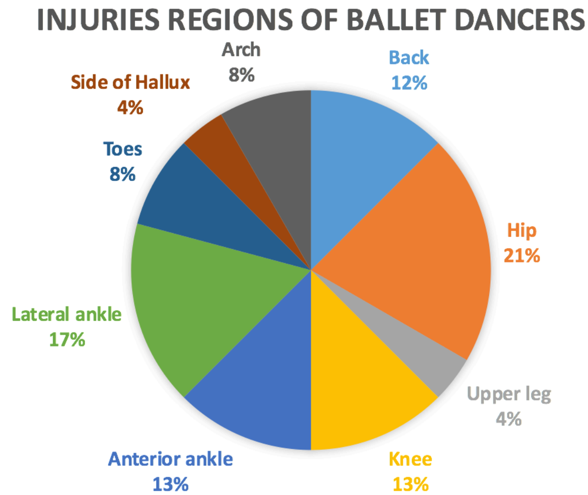

Figure 4-7. Injuries Regions of Ballerinas.

For the pain regions in high heels as shown in Figure 4-8 and Figure 4-9, the following observations can be made;

1. Ball of foot is the most common pain region for both groups.
2. More ballerinas feel pain in side of hallux area by 11%.
3. Although as much as 24% of the control group feel discomfort in the toe area, none of the ballerinas have mentioned that.

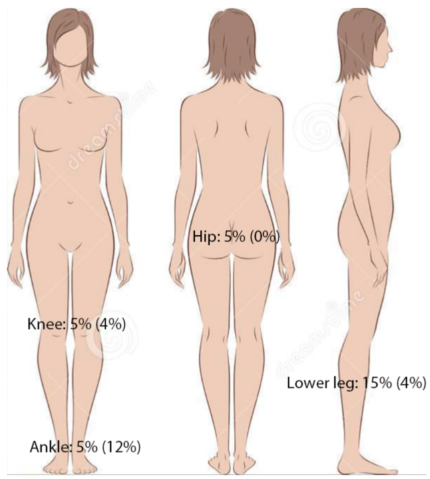

Figure 4-8. Pain Regions in High Heels (on the body).

Adapted from Female Silhouette, In *dreamstime*, n.d., Retrieved March 12, 2016, from https://www.dreamstime.com/royalty-free-stock-images-female-silhouette-vector-illustration-figure-front-back-side-views-image39420499

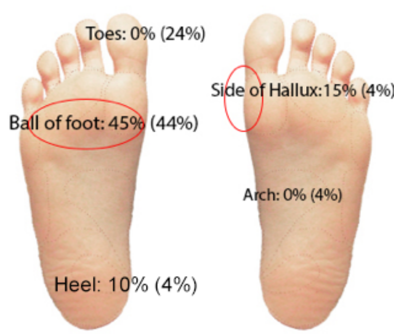

Figure 4-9. Pain Regions in High Heels (on the foot).

Adapted from Foot Pain Identifier, In *footEducation*, n.d., Retrieved March 12, 2016, from http://www.footeducation.com/foot-pain-identifier/

Note. In the diagrams of pain regions in both groups when they are in high heels (Figure 4-8 & Figure 4-9), the number in brackets are the percentages of control group who feel pain in the corresponding area. The number without are the percentages of the ballerinas.

Pain regions in pointe shoes was also asked during the personal interviews with ballerinas (Figure 4-10). The result shows that when wearing pointe shoes, the toe area takes up the highest percentage as much as 25%, while in the third observation listed above, none of the ballerinas have reported any discomfort in the toe area when wearing high heels (24% for the control group).

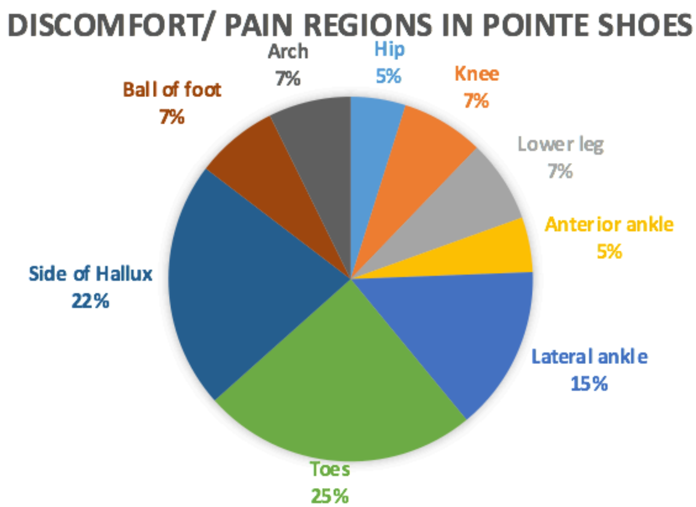

Figure 4-10. Pain Regions in Pointe Shoes.

Table 4-15 shows the correlations between comfort perception in pointe shoes and ballet related experience. The comfort perception in pointe shoes is highly correlated with pointe experience. The longer the pointe experience is, the lower the Likert scale rating (less discomfort or pain) is. The comfort perception is also correlated with ballet experience and peak time practice frequency (usually in high school years).

The longer the ballet experience is, the higher practice frequency the ballerinas had at the time they practiced most intensely, the lower the Likert scale rating is.

Table 4-15. Correlations of Likert Scale Rating of Discomfort Level in Pointe Shoes and Ballet-related Experience

Correlations

		Ballet Experience	Pointe Experience	Peak Time Practice Frequency (per month)
Likert Scale Rating (Discomfort level in pointe shoes)	Pearson Correlation	-.462*	-.584**	-.402*
	Sig. (2-tailed)	.010	.001	.028
	N	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

The box plot (Figure 4-11) shows the Likert scale rating difference when the participants switched from running shoes condition to high heels condition, which indicates the comfort perception change. The result shows that ballerinas have smaller perception change than the control group.

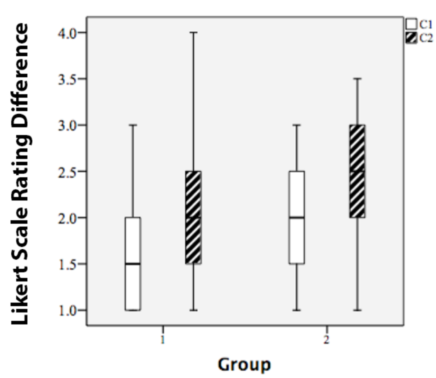

Figure 4-11. Box Plot of Likert Scale Rating Difference of Discomfort Level.

Note. C1 represents comfort perception change from running shoes to high heels in standing conditions; C2 represents comfort perception change from running shoes to high heels in walking conditions.

4.5 Discussion

14 out of 15 participants use toe pads in their pointe shoes while performing or practicing, some of them would use lamb wool and gel toe spacers. It indicates the normality of the pain or discomfort in pointe shoes that most of the ballerinas in this study choose not to wear them alone. Only one ballerina claimed that she has never used any kinds of paddings since the first time she put on her pointe shoes, while all the other ballerinas said they have to use paddings in pointe shoes or it would hurt too much. This particular ballerina also reported no pain or discomfort in pointe shoes, which caught the researcher's attention. Although it is possible that a single case of a ballerina with no pain in pointe shoes can be an outlier, further investigation on this case might provide useful information for future study. Based on the pie chart (Figure 4-12), for most of the ballerinas, side of hallux and toes are the two regions that hurt most when dancing in pointe shoes. After comparing the foot measurements of this ballerina to those of other ballerinas, it appeared that she has the smallest first toe angle (5.4°) among all the ballerinas, which is smaller than the group mean 12.36° by 56%, and a relatively large fifth toe angle.

Figure 4-12. Foot Shape Image of One Ballerina.

The correlation of the first toe angle and comfort perception in pointe shoes was then analyzed (Table 4-16). Although the first toe angle here does not have a linear relationship with the comfort perception, based on the scatter plot of Likert scale rating and toe #1 angle (Figure 4-13), hypothesis can be proposed that, with larger first toe angle, the ballerinas tend to feel more discomfort in pointe shoes. However, since this is only one sample, the theory needs to be proved or disproved by further research.

Table 4-16. Correlations of Likert Scale Rating of Discomfort Level in Pointe Shoes and First Toe Angle

Correlations

		toe#1angle	LikertRating_in PointeShoes
toe#1angle	Pearson Correlation	1	.342
	Sig. (2-tailed)		.064
	N	30	30
LikertRating_inPointeShoes	Pearson Correlation	.342	1
	Sig. (2-tailed)	.064	
	N	30	30

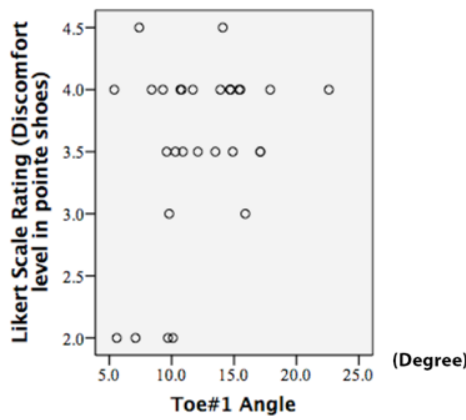

Figure 4-13. Likert Scale Rating of Discomfort Level in Pointe Shoes.

In conclusion, to answer the first research question, ballerinas are different from the control group in their foot flexion angle in demi-pointe position. The ballerina group has a much smaller foot angle in demi-pointe position which indicates that the ballerinas tend to have a larger flexion of the metatarsophalangeal joint (the joint at the base of the toe) in demi-pointe position. This result indicates that the flexibility of the metatarsophalangeal joint can be trained overtime probably by doing the demi-pointe position in ballet dance.

As answers to the second research question, no significant group main effect was found in either peak PCP or in COF excursions. However, a region*group interaction in log peak PCP in standing condition and a shoe*group interaction in log peak PCP in walking condition were found. A shoe*group interaction in normalized A-P excursion in walking condition was found as well. In standing, the peak pressure in forefoot region has no difference than in heel region in ballerinas' group, while in the control group, the peak pressure in heel region is larger than in forefoot region. According to one of the ballerina participants, ballerinas tend to put their center of mass of body more forward, which is consistent with the result. In walking, the increase of peak PCP from running shoes condition to high heels condition is smaller in ballerinas' group than in the control group, while the decrease of A-P excursion from running shoes condition to high heels condition is larger. All the ballerinas participating in this study have claimed that they think they have better control and balance walking in high heels. The larger decrease of A-P excursion from running shoes to high heels in ballerinas' group could support the ballerina group's belief that they don't lose body balance while walking in high heels as they could have maintained body balance with smaller A-P excursion.

To identify the pain regions and comfort perceptions of the participants, as proposed in the third research question, the result shows that ballerinas tend to have smaller perception change than the control group from running shoes condition to high heels condition. It means they tend to feel less pain or discomfort when switching to high heels condition. In terms of the pain regions of ballerinas, the result of the toe area taking up the highest percentage as much as 25% in pointe shoes, and 0% in high heels (24% for the control group) strongly suggests that ballerinas are so used to the compression in the toe area that the pointy high heels don't bother them at all.

For the last research question, the foot flexion angle in demi-pointe position has a strong correlation with pointe experience, indicating that the more one have danced on pointe, the higher up one can get when standing in demi-pointe position. Moreover, the comfort perceptions of ballerinas in pointe shoes is highly correlated with pointe experience. The longer the pointe experience is, the lower the Likert scale rating (less discomfort or pain) is, which means the longer the pointe experience a ballerina has, the less pain or discomfort they feel in the pointe shoes. The result is consistent with the interviews with the ballerinas: as the time goes by, 14 out of 15 dancers get more and more used to the pointe shoes and don't feel as much pain.

Chapter 5 Conclusion

A significant difference was found in foot flexion angle in demi-pointe position between ballerinas and control group. Ankle plantarflexion in demi-pointe position depends highly on pointe experience. Due to the similarity of the foot position when standing in demi-pointe position and standing in high heels, inference can be made that ballerinas might be able to better adjust to high heels with higher heel height than others, which corresponded to the fact that the ballerinas in this study tend to wear heels with higher height than the control group. The causative factor for the differences between two groups in the increase of peak PCP from running shoes condition to high heels condition in walking and the decrease of A-P excursion from running shoes condition to high heels condition in walking is still unknown due to the different types of running shoes the participants were wearing. However, if the assumption of the same running shoes condition stands, it may imply that the ballerinas have better control and balance than other population.

In this study, the ballerinas' group perceived less pain or discomfort when they switched from running shoes to the high heels condition. They also perceived less pain or discomfort in pointe shoes as their pointe experience increased. It can be interpreted in two possible ways. Either repetitive pointe work results in the insensitivity to the pain in ballerinas, or it can be due to the mechanical changes in the ballerinas' feet having spent so many hours in that plantarflexed posture. If the first interpretation is correct that ballerinas tend to perceive less pain or discomfort in the foot even when having the same level of foot pressure and mechanism as others, this insensitivity to foot pain is likely to be consequences of the long-term use of pointe shoes. It has been observed that the comfort perception of pointe shoes is highly dependent on pointe experience. Interviews conducted with the ballerinas also revealed that greater pointe experience and pointe shoe familiarity led to less pain and discomfort while wearing pointe shoes. Moreover, the pain or discomfort was also inversely correlated with peak time practice frequency. In this case, based on the decreased pain sensitivity and increased likelihood to underestimate potential foot injuries, high heels wearing can be harmful for ballerinas, as they may be less careful or aware of potential foot injuries, thus increasing injury risk. Pointe users, especially those with prior foot problems, should be more careful when wearing high heels. For example, they may consider using a pair of high heel inserts to avoid the chronic stresses on their feet. However, if the latter mechanism is mainly responsible, the knowledge of ballerinas appearing to have advantages in balancing their bodies in high heels can be added to the field of study. Future study is suggested to help clarify the responsible cause.

During the interviews, four of the ballerinas reported that they chose to ignore pain and returned to training even after their therapist at the time suggested for them to rest longer or stop dancing altogether. Therapists, parents, and ballet teachers should pay more attention to ballet students who have had injuries since they tend to “ignore the pain” and “pull it through”. Based on this observation, pointe shoe developers and orthotic product makers should further investigate the pain regions that ballet dancers tend to ignore to develop pointe shoes, paddings, or orthotic products that are better aimed to prevent or alleviate injury.

However, this study has a few limitations. Firstly, the sample size is small due to the difficulty of recruiting ballerinas in the area of research. This limited the statistical power to predict the causal effect in the research study and requires further studies with a larger population for confirmation of findings of this study. Secondly, the age range is very narrow in this study; future study with a wider age range could potentially provide more information. Thirdly, this study recruited only participants without diagnosed foot deformities and past surgeries in order to both safely conduct the experiment with high heels and also help control for the confounding factors that may influence data quality. Nevertheless, more research needs to be done to by recruiting a larger population of ballerinas with more variability, which can provide additional meaningful information for ballet students, educators, and products developers. Although high heels wearing frequency is almost the same in the two groups, ballerinas tend to wear heels with higher height than the non-ballerinas, which means they are more used to wear high heels with high height. It could also affect some of the results in this study to some extent. In addition, future studies with a paired sample test may provide additional meaningful information and verification of the findings of this study. Moreover, whether pointe work and pointe shoes wearing increases the risk of hallux valgus is still under discussion. Although the first toe angle is not significantly different for the two groups in this study, it is very close to the statistical significance level, which further research could clarify upon.

APPENDIX 1 QUESTIONNAIRE

Part 1.

Age		Height		Ballet starting age		Pointe quitting age	
Foot Size		Weight		Pointe starting age		Ballet quitting age	

1. How long have you been dancing?
2. How often do you dance?
3. How long/ how often have you been wearing pointe shoes?
   Are you still dancing on pointe? If not, when did you quit and how old were you?
4. How did you feel about wearing it, comparing without pointe shoes?
5. Do you use paddings in pointe shoes? If yes, what kind of padding do you use and where do you put it on the shoes? When do you start to use it and how does it help?
6. Does your teacher have any recommendations regarding wearing pointe shoes and daily shoes? If any, please explain.
7. What are the criteria of your pointe shoes, (considering the right size, fit and functionality)?
8. How do you purchase your pointe shoes?
9. Have you been dancing in heels?
10. Do you have any foot problems?

If any:

11. Which part of the foot do you feel most troubled? Please circle the pain area and briefly describe it. When do you usually feel the pain or discomfort?
12. Can you describe specific movements causing the issues?
13. Are you seeing a podiatrist (or a regular doctor) or have you seen one before? If yes, what was the doctor's diagnose and suggested treatment?
14. Do you use orthotic products, if any, what kind, and when did you start to use it?
15. If not/seldom use them or didn't use them at the beginning of perception the foot pain/comfort, why?
16. Do you wear high heels? Why or why not?
17. If you do, how many days do you wear them per week on average? Approximately how many hours for each day? Please indicate the typical height of your high heels by selecting from the following:
    a) 0~2.5inches (6.4cm)
    b) 2.5~3.5inches (6.4~8.9cm)
    c) 3.5~4.5inches (8.9~11.4cm)
    d) More than 4.5 inches (11.4cm)
18. Have you ever experienced any foot pain/discomfort while wearing high heels? If any, please indicate the pain/ discomfort area and the degree of the pain/discomfort.
19. On a degree of 1-5, what would you use to describe your pain level in these areas? (Indicates 0 if having no pain)

    (1) Wearing pointe shoes:

Very comfortable	Comfortable	Neutral	A little uncomfortable	Very uncomfortable
1	2	3	4	5

    (2) Wearing pointe shoes in the specific ballet movement you mentioned in Q12:

Very comfortable	Comfortable	Neutral	A little uncomfortable	Very uncomfortable
1	2	3	4	5

    (3) Wearing your own high heels:

Very comfortable	Comfortable	Neutral	A little uncomfortable	Very uncomfortable
1	2	3	4	5

Part 2. During experiment:

Please indicate the pain or discomfort area, if any, and describe your perception during the task.

(1) Wearing your own running shoes while standing:

Very comfortable	Comfortable	Neutral	A little uncomfortable	Very uncomfortable
1	2	3	4	5

(2) Wearing your own running shoes while walking on treadmill:

Very comfortable	Comfortable	Neutral	A little uncomfortable	Very uncomfortable
1	2	3	4	5

(3) Wearing our high heels while standing:

Very comfortable	Comfortable	Neutral	A little uncomfortable	Very uncomfortable
1	2	3	4	5

(4) Wearing our high heels while walking on treadmill:

Very comfortable	Comfortable	Neutral	A little uncomfortable	Very uncomfortable
1	2	3	4	5

APPENDIX 2 IRB APPLICATION APPROVAL

Cornell University
Office of
Research Integrity and Assurance

East Hill Office Building, Suite 320
395 Pine Tree Road
Ithaca, NY 14850
p. 607-254-5162
f. 607-255-0758
www.irb.cornell.edu

Institutional Review Board for Human Participants

TRIENNIAL PROTOCOL APPROVAL- NO FEDERAL FUNDS

To:	Qinwen Xu
From:	Carol Devine, IRB Chairperson Carol M. Devine
Protocol ID#:	1510005933
Protocol Title:	The Relationship Between Ballet Dancers and High Heels
Approval Date:	December 04, 2015
Expiration Date:	December 03, 2018

Cornell University's Institutional Review Board for Human Participants (IRB) has reviewed and approved the inclusion of human participants in the research activities described in the protocol referenced above.

<u>**Special Conditions for Triennial Approval of this Protocol:**</u> This protocol was granted approval for three years until **December 03, 2018** as it does not involve federal funding and is therefore eligible for Triennial review under the IRB policy #21 (www.irb.cornell.edu/policy). As Principal Investigator for this project, you are responsible for informing the IRB and seeking re-review if at any point during the course of this project, Federal funds may be used to support any part of it. Failure to seek timely review and approval could result in an inability to use research data for the purposes of the Federal grant. Please refer to IRB policy #21 (www.irb.cornell.edu/policy) for more information.

The following personnel are approved to perform research activities on this protocol:

- Qinwen Xu
- Huiju Park

This approval by the IRB means that human participants can be included in this research. However, there may be additional university and local policies that apply before research activities can begin under this protocol. It is the investigator's responsibility to ensure these requirements are also met.

Please note the following important conditions of approval for this study:

1. All consent forms, records of study participation, and other consent materials **must** be held by the investigator for **five years** after the close of the study.

2. Investigators must submit to the IRB any **proposed amendment** to the study protocol, consent forms, interviews, recruiting strategies, and other materials. Investigators may not use these materials with human participants until receipt of written IRB approval for the amendment. For information about study amendment procedures and access to the Amendments application form, please refer to the IRB website: http://www.irb.cornell.edu/forms.
3. Investigators must promptly report to the IRB any **unexpected events** involving human participants. The definition of prompt reporting depends upon the seriousness of the unexpected event. For guidance on recognizing, defining, and reporting unexpected events to the IRB, please refer to the IRB website: http://www.irb.cornell.edu/policy.

If the use of human participants is to continue beyond the assigned approval period, the protocol must be re-reviewed and receive continuing approval. As the Principal Investigator it is your responsibility to obtain review and continued approval before the expiration date. Applications for renewal of approval must be submitted sufficiently in advance of the expiration date to permit the IRB to conduct its review before the current approval expires. Please allow three weeks for the review.

Any research-related activities -- including recruitment and/or consent of participants, research-related interventions, data collection, and analysis of identifiable data -- conducted during a period of lapsed approval is unapproved research and can never be reported or published as research data. If research-related activities occur during a lapse in the protocol approval, the activities become a research compliance issue and must be reported to the IRB via an unexpected event form (www.irb.cornell.edu/forms).

****If you do not plan to renew your protocol approval in three years, please provide the IRB with a Project Closure form. A link to the Project Closure form can be found at http://www.irb.cornell.edu/forms/.**

For questions related to this application or for IRB review procedures, please contact the IRB office at irbhp@cornell.edu or 255-6182. Visit the IRB website at www.irb.cornell.edu for policies, procedures, FAQs, forms, and other helpful information about Cornell's Human Participant Research Program. Please download the latest forms from the IRB website www.irb.cornell.edu/forms/ for each submission.

Cc: Huiju Park

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