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The Biomechanics of the Tendu in Closing to the Traditional Position, Pli#233; and Relev#233;

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The Biomechanics of the Tendu in Closing to the Traditional Position, Plié and Relevé

by

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of the requirements for the degree of
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DEDICATION

This is dedicated to my parents, Michael and Margaret, who have supported me and encouraged me to reach my goals.

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ABSTRACT

Dancers spend many years practicing repetitive movements in order for their bodies to gain flexibility, strength and muscle memory. This thesis investigated the biomechanics of a dance student's knee motion during a tendu to the front in first, third, and fifth positions. A dancer will often perform 75 or more tendu closing actions during one technique class – particularly in ballet technique. During a tendu the moving foot moves along the floor but the toes never leave the floor. The tendu is used to strengthen the leg muscles, particularly the quadriceps and gluteal muscles. Flexion/extension, abduction/adduction, and rotation angles of the knees during a traditional flat footed closing were compared to the knee angles during plié and relevé closing. These movements were performed by 10 healthy dance students from USF. The dancers' movements were tracked using the VICON Nexus motion analysis system and 27 passive reflective markers placed on bony landmarks. Visual 3D software was used to calculate the knee angles. There were statistically significant the differences between knee angles during the traditional and plié closings and between the relevé and plié closings for all positions. There were only 4 conditions in which there was statistical significance between traditional and relevé closings. Knee flexion difference between the traditional and relevé closings was unanticipated, as the expectation of the tendu movement is to maintain a fully straight knee throughout the full range. This result suggests that the students may be bending the knees to achieve greater outward rotation, particularly in the third and fifth positions. The plié had the largest range of motion (ROM) for all of the angles tested including abduction/adduction in which the subjects used the abduction at the knee to hold the feet in a turned out position. The collected data gives better

insight into the biomechanics of the knee movement and will be used as feedback for improving muscular strength and preventing injuries in dancers.

CHAPTER 1: INTRODUCTION

1.1 Problem Statement

Dancers perform many repetitions of the tendu throughout their dance training and warm ups for each class. Specifically, in ballet training, the dancer may perform 75 or more repetitions with one single class. This thesis comparatively examines knee biomechanics of the tendu in three different closings (traditional, plié, and relevé) and in three different positions: 1st, 3rd, and 5th. This study is relevant to dance training regimens by examining the way in which knee movement is employed in traditional training practices and its implications to injury trends in dance.

1.2 Objectives of the Thesis

The objective of this study was to analyze the biomechanics of the tendu dance movement and assess injury risk. In particular, this study sought to analyze the knee biomechanics between three different types of closing strategies for the tendu movement in dance through motion analysis techniques. The intent was to determine if changing the closing strategy could alleviate the extent of external rotation occurring at the knee, and to determine which position, 1st, 3rd, or 5th is most demanding and potentially injurious in terms of knee kinematics. One way that this can be done is by making of a model of the kinetic chain of the ankle to knee to hip to spine. This kinetic chain of reaction model could help the dancers understand how they are moving. One of the things the USF dance instructor wanted to examine was a method of doing a modified tendu do get the

same training of the muscles especially in fifth position and thus reducing the possibility of injury to the dances.

1.3 Background

Dance requires a high degree of study and training to become proficient [1]. According to Bronner dance is defined as the complex organization of multi-joint movements [1]. There has been very little studied in the lower extremities of dancers as stated by Bronner [1] . With dance training comes the ability to make the body and its joints more flexible. This can be seen in the way the dancers move their body and the angles at which they can move their limbs. One way to see the efficiency of a dancer is to look at the spatial and temporal coordination. This coordination is how the dancer know where they are in the field of movement and their timing with the music [1]. This time-space coordination comes into play when the movement of the dancers starts to involve rotation of the whole body, or a turn. The dancer uses kinesthetic or visual movement to start and stop the turn at the appropriate time. The dancer has more postural control and completes complex coordinated movements better than a non-dancer [2].

There has been a lot of research using motion analysis in the area of sports [3]. However, little research is being done on the subject of dance using motion analysis to examine how different positions act on the body. Most of the dance research using motion capture involves constructing a model of the dancer in the computer software and using the information from the motion analysis to make computer animations [4]. As interesting as these computer animations can be, they will not help the dancer understand the mechanics of the dance motion because they are geared towards imitation of human skills by robots. There are some examples of motion analysis research in dance utilized for better understanding the biomechanics of the dancer's

movements in relation to dance skill development/practice and injury prevention. For instance, in the Bronner study, the researchers looked at the passé which is a ballet movement where dancers start in first position and move one foot up to the knee with the toe pointed and then back to the floor [1]. In the analysis of this movement, the researchers had to look at the kinetic chain which consists of the ankle, knee, hip, and the spine [5],[6]. The dancer should be educated about the model of the kinetic chain of the spine and the lower limbs. This information could be important to the dancer because the pronation or supination of the tarsus gives increased stress on the rest of the kinetic chain.

1.3.1 Dance Background

One of the basic premises of ballet dance is the demand for turnout, or the outward rotation of the hip. The larger the turnout of the dancer the better, with a turnout of 180 degrees considered a perfect turnout. Turnout is when the legs are rotated so that the heels are touching and the toes are pointed outward and this rotation should ideally come from the hip. This degree of turnout is not normal in the average population. Some of the anatomical conditions required at the hip to produce a turnout are "ligament laxity, a long femoral neck, a low femoral neck-shaft angle, and a low angle of femoral anteversion" (Watkins *et al*, 1989, p. 148). When some of these conditions are not a part of eh dancer's natural anatomy, which is true of most dancers, the dancer will try to compensate by adding rotation at the knee and/or ankle and this tendency results in the commonly documented lower body injury trends seen in dancers [7]. This study hopes to contribute further insight into injury prevention for dancers with specific attention to the knee joint. The study examines the angles of the knee to see if the dancers are rotating at the knee and what impact the different closings will have on the verus and valgus angles of the knee. Some of the statictics for injuries in dances stated by Gamboa *et al* are 16.1% of the elite pre-

professional dancers they studied had injuries to the knee with 32 to 51 percent of the dancers studied were injured each year for five years and this was for all injuries [8].

One of the most fundamental movements of ballet technique is the tendu (Merry Lynn Morris, personal communication). A tendu (Figure 1) is a movement where the foot is extended and never leaves the floor. The foot moves to the front, side, and back from the first or fifth position. The tendu is the first movement in dance where the dancers learn to stand with their weight on one leg. It is very important for the dance student to learn this movement correctly from the beginning of their training.

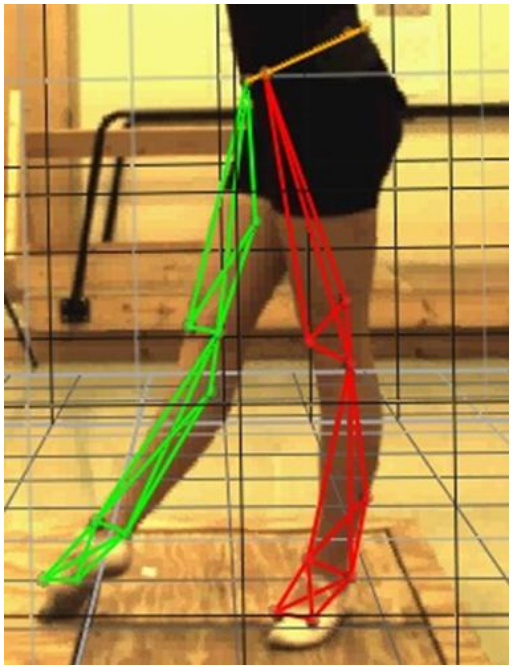

Figure 1: A Tendu

There are many ways the tendu can be done incorrectly and one is to pronate the moving leg. This will result in added stress on the ankle and the knee. Another way is to pronate or supinate the supporting leg; this can also result in added stress on the ankles and knees of the supporting leg. One of the other ways that the tendu can be performed incorrectly is to have the

moving foot move through the air and landing at the end of the move, this would then be a dégagé and not a tendu. The last way is by moving the moving leg correctly through the tendu movement on the floor, but in the return closing position over rotating or pronating the foot, so all of the pressure goes on to the side of the big toe and not onto the top of it.

Dance training traditionally involves five basic positions of the feet, as codified by balletic traditions. All of the basic positions have the feet turned out, with the feet pointing in opposite directions. This thesis will focus on first, third, and fifth positions because the tendu movement is usually performed closing to all of these positions, with 1st, and 5th positions being the most commonly used in ballet training. Second and fourth positions involve the feet spaces separately from one another, and therefore, the tendu movement is not particularly useful it the feet and legs are already at a distance from one another because the leg has nowhere it go spatially. The first position (Figure 2) is with the feet aligned and the heels are touching with the knees straight.

Figure 2: First Position

Second position (not pictured) is the same as first with feet spaced approximately twelve inches apart. Third position (Figure 3) is with one foot in front of the other and the heel at the arch of the other foot.

Figure 3: Third Position

Fourth position (not pictured) is where the feet are about twelve inches apart and there are two types: open where the heels are aligned, and closed where the heel of the front foot is aligned with the toe of the back foot. And lastly there is fifth position (Figure 4) where the feet are touching and the heel of the one is aligned with the toe of the other [9].

Figure 4: Fifth Position

There were three different dance closings performed for this study, the traditional, plié and relevé. The traditional closing (Figure 5) is generally the most common closing that dancers practice in dance class (Merry Lynn Morris, personal communication). This is a straight leg closing and in which the feet close flat on the floor. The dancer is expected to maintain a straight leg/knee throughout the entire trajectory of the movement from starting position to closing position. However, this study examined the extent to which dancers are actually able to maintain an extended knee throughout the duration of the tendu movement and forthcoming implications.

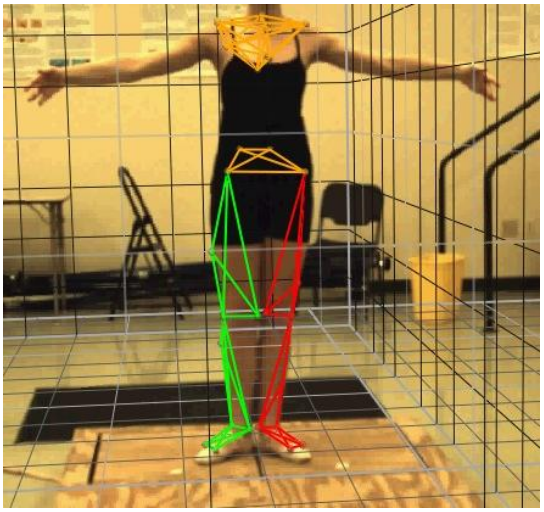

Figure 5: Traditional Closing

The next closing for the dancers to perform was the plié (Figure 6). The plié is defined as a bend of the knee and the dancers did a demi plié which is a small bend of the knee. The instruction for the dancers for this closing was to extend their leg for the tendu and draw the leg back into a plié position without re-straighten the leg. The reason for looking at the plié closing was the plié allowed the dancer to close without straightening the leg and therefore hypothetically should avoid the "screwing of the knee" which often occurs in the traditional closing [10].

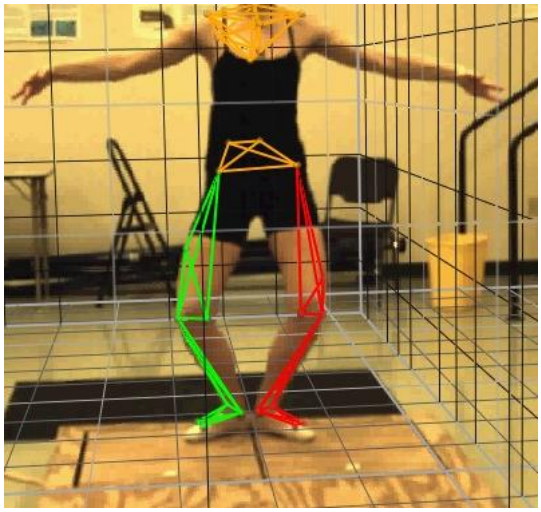

Figure 6: Plié Closing

The last closing for the dancers was the relevé (Figure 7). The relevé is when the dancer lifts onto the ball of their foot (metatarsals) keeping the legs straight. The instruction for the dancers for this closing was to extend their leg for the tendu and then close to the relevé with straight leg, followed by the next tendu movement. The reasoning for looking at the relevé closing was the relevé, heightens the center of gravity, giving the dancer space to bring their leg back without bending the knee. In the traditional closing, dance instructors commonly instruct the students to lift at the hips/pelvis to create space for the leg to come back to the body straight; although, dancers often cannot create enough space to close regardless of the amount of lifting they do, and must strategically bend the knee to accomplish the close (Merry Lynn Morris, personal communication). The relevé closing was specifically employed in this study to address this problem and attempt another possible solution for the closing by having the dancer rise onto the balls of their feet.

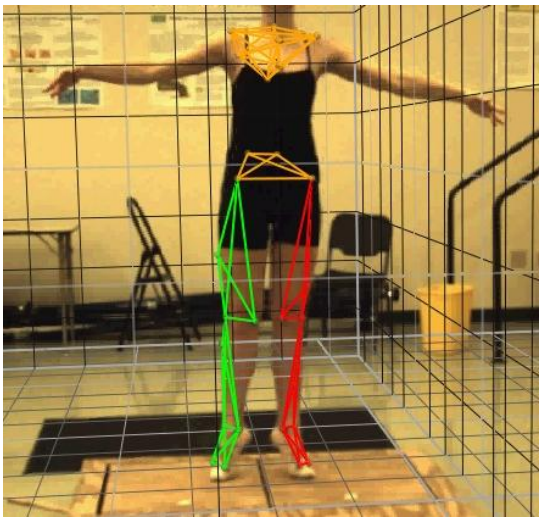

Figure 7: Relevé Closing

1.3.2 Angles of the Knee

One of the biomechanical aspect this thesis analyzed the angles of the knee including the flexion/extension, abduction/adduction also called varus and valgus, and rotation. It is important to know if the knee is in rotation or not, because repetitive and excessive rotation of the knee under particular condition contributes to the prevalence of the knee injuries in dancers. (Merry Lynn) This can be difficult to tell sometimes from simple observation. Rotation occurs when the knee is in flexion and the ligaments are relaxed [11]. In knee extension one has to look at the tuberosity and if it is moving medially or laterally, then the rotation is at the hip and not the knee. Because the foot will also turn with these movements, it is important to focus on the movements of the tibial tuberosity and not the feet [11]. Another angle that is of interest, but not looked at for this study, is Q-angle, which is the angle of the vertical line straight up the leg and the line of the femur. Normal Q-angle for males is 13 degrees and for females is 18 degrees , with the knee in extension [12]. When looking at the angles of the knee most flexion/extension of the knee is 140 degrees of flexion and only about 5 to 10 degrees of extension, which would be a hyperextension of the knee [13]. Some dancers have hyperextension of the knee also called genu recurvatum in anatomical terms and is an angle significantly beyond 180 degrees [11]. Hyperextension comes from a looseness of the posterior ligaments and capsule and it stretches the cruciate ligaments [14]. Another angle important to the knee is the genu varum which is normal between 170 to 175 degrees and is called knock-knee at 165 degrees or less and bow-leg at 180 degrees or greater [13]. Then this means that the normal range of motion for the adduction/abduction of the knee is only five degrees. The last angle of interest is the rotational angle of the knee which is normally about 10 degrees of external rotation in full extension and

with knee in flexion of 90 degrees total rotation permits 40 to 50 degrees of rotation with an external to internal ratio of 2:1 [13].

1.4 Prior Research

The Gregersen *et al* study was looking at the varus and valgus angles of the knee that shows the movement on the knee. These are the angles of the knee that represent rotation and also are called adduction and abduction. Because of the kinetic chain, the varus valgus can be manipulated at the hip or ankle, as in dance or only at the ankle, as in cycling. The study from Gregersen *et al* looked at manipulating the inversion and eversion of the foot and seeing what effect it had on the knee angles. Their study looked at the non-driving leg with focus on changing the angle of the foot with the pedal to see how it changed the angles of the knee. The researchers found that peak varus knee moments decreased from the neutral position when the foot was everted and increased with the foot in an inverted position. This shows that the way the foot is placed on the pedal can affect the reaction at the knee [15]. The reaction of the foot to the ground can be important when it comes to looking at dance. The way the foot of a dancer makes contact with the ground can change the forces that are exerted on the ankle, knee, and hip. When looking at the ankle the placement of the foot can make the foot go into pronation or supination that will make the knee have more rotation which can be seen in the varus and valgus angles of the knee. The Gregersen *et al* study used reflective markers to calculate the angles of the knee [16].

By contrast the Watkins *et al* study used a protractor to measure the angles. The turnout was measured from the reference line of one foot to the reference line of the other foot for young, pre-professional, college and professional ballet dancers. The reference line is a line from the mid-heel point to the side of the second metatarsal [7]. The angle of deviation (AOD), is the

angle between the tibial tuberosity and the reference line. The Watkins *et al* studied angle in the first, right fifth, and left fifth position [7]. It found that in first position the young group had the greatest AOD and the college group had the smallest AOD. For first position, the AOD for the right leg was greater than the left leg. This was also true for right fifth and left fifth. The largest AOD for all groups was on the right leg [7]. For turnout there were differences in the angles with the young group having the most and the college age having the smallest, and the pre-professional and professionals having about the same degrees of turnout. This was for first, right fifth and left fifth [7]. One interesting thing the study found was that the greatest turnout was in fifth position; they believe this is because the dancers can brace one leg against the other [7]. The young dancers have the greatest turnout and this may be because they are forcing the turnout at the knee and ankle, and this could cause more stress on the knee and ankle [7]. From the Watkins *et al* study the turnout of the dancers changed with the difference level of training and is why the dancers of this study performed their tendus in their comfortable turnout. Also Watkins *et al* only used hand measuring tools, were as this study will be using a motion analysis system.

As stated previously turnout is where the hips are rotated externally to form a 180 degree line across the feet. This ability to turn the feet out to 180 degrees is one of the essentials of a successful dancer. When this turnout is not achieved fully by the hip, then the dancer will use other joints, knees and tarsal, in the lower leg to get the desired turnout. This can result in more injuries to the dancers and is sometimes called "screwing the knee" in ballet circles. Bennell *et al* (1999) defines "screwing the knee" as the "hip and knees are flexed and then [they] force the hips and knees into extension without moving the feet" (p. 340). Screwing the knees can cause torsion in the knee and ankles. The Bennell *et al* study was trying to look at whether the flexibility in professional dancers is trained or if these dancers are genetically more flexible: so

the question is does training the dancer in external rotation of the hip, create more flexibly in the dancer or is a dancer born with the external rotation ability. The study looked at children age 8 to 11 in ballet dance classes and, as a control group, non-dance children of the same age. The study looked at hip and ankle range of motion and hip muscle strength in young novice female ballet dancers and the control group at ankle dorsiflexion and external rotation of the hip [10]. One of the results the study found was that the controls had a greater external rotation of the hip than the student dancer. The dancers and controls had the same turnout. But the dancers had a greater ankle dorsiflexion than the controls; this was both in centimeters and degrees. The Bennell *et al* study measures the movement of the subjects by clinicians moving the joints, this could not be a true representation of the subject's moment in a dance move. For the thesis will be using the motion analysis system. From looking at turnout the next study will look at the grand plié.

One of the studies that was reviewed for this study was on the grand plié looking at the external longitudinal rotation from York University. This study looked at external longitudinal rotation (ELR) in 10 dancers in a professional company. In dance training a movement is performed many times in rehearsal. This is when injury can occur in dancers, because of the constant repetition needed to master the movement and for the muscle memory to take place [17]. Injury can come from the pushing of the bodies' range of motion to the extreme. The reason some dancers might push their bodies to this extreme is for the aesthetic of classical ballet. This is when dancers would force a greater turnout by not using the proper alignment of their bodies [17]. In the study dancers performed a grand plié, which is when the dancers have their feet turned out and bend their knee so that their heels are lifting off the floor. For this study the plié was performed in three classical ballet positions, second, third, and fourth. Barnes *et al* believes that this movement can be harmful to the human body because of the compressive

forces and the excessive range of motion created by the grand plié [17]. This study found that the highest ELR was at the bottom of the grand plié and the positions of the legs did not have a factor in this [17]. It was also found that the ELR was higher at the bottom of the grand plié than in the straight leg position. The researchers found that ELR increases with knee flexion [17]. And additional finding from this study was that there is symmetry of the ELR in the grand plié and this is a higher risk in the third and fourth positions than in second position [17]. This does make sense because in third and fourth positions the legs are closer together. In third position they are touching and in second position, the legs are spread apart. This study will also be looking at rotation both internal and external rotation were as the York University study only was interested in external longitudinal rotation. Also their study second, third, and forth position two of these closing have the feet apart were as the dance study for this thesis has to feet touching in all three of the positions.

Clearly there is a lot of training that goes into being a proficient and healthy dancer. Dancers must have knowledge of many movements and positions that can place strain on their bodies. They also need to know how to efficiently move their bodies, so as not to go outside the limits of their bodies. The idea of accommodating perfect turnout can place stress on the dancers' bodies if they do not have the anatomical conditions for a 180 degree turnout, especially as they move into fifth position. From the literature review, there have been a few studies on how the knee moves in some dance positions. None of these studies have looked in the motion of the knee when closing to the tendu. Even though one study did look at the grand plié, none have analyzed the plié and relevé closing compared to the traditional closing that has been taught to dancers from the beginning of their training. This thesis analyzed the knee angles of ten healthy dance students performing a tendu in first, third, and fifth positions. It will be looking at all of

the angles of the knee which are flexion/extension, abduction/adduction, and rotation of the knee while closing to the traditional, plié, and relevé closings.

CHAPTER 2: METHODS

2.1 Population

The dance study was performed with ten (10) healthy dancers from the University of South Florida (USF) School Of Theater and Dance which is part of the College of the Arts. A flyer was distributed to the student via email by the study coordinators to the prospective study participants. Some study participants were introduced to the study through one of the dance classes taught at the university.

The ten dance students were between the ages of 19 and 23 and had no acute injuries of the lower limb. The study was open to both male and female dance students, but only female dancers actually participated in the study. Only dance majors in the dance program at USF where included for this research due to the similarity in training variables and age range, lending to better reliability and validity of results. No non dance students were used in the study because the study was to address an issue within the dance population. The students came from the levels 1-IV in ballet and levels 1-IV in modern; this was in order to provide a cross-section of skill levels for the research (intermediate to advanced dance students).

The participants' wore the same clothing as they would in dance class. This was tight fitting clothing on the upper body and legs with the knees not covered and wearing soft ballet shoes. So the subjects' wore socks if they did not have ballet shoes. This was because the trials were performed on unfinished wood. After they signed the informed consent, their age (20.8 ± 1.23 years), height (1.62 ± 0.0458 m), weight (56.85 ± 7.98 kg), ASIS distance (248.3 ± 22.05

mm), right (81.11 ± 6.98 mm) and left (81.11 ± 6.98 mm) knee distance, years dancing (13.1 ± 3.27 years) , and level of dance at USF ballet (2.3 ± 0.64) and modern (2.5 ± 0.5) was recorded.

Table 1: Dance Subject Information

Subject ID	Age	Height (m)	Weight (kg)	ASI distance (mm)	Right Knee distance (mm)	Left Knee distance (mm)	Years Dancing	Level: Ballet	Level: Modern
AC001	21	1.7	79	285	not taken	not taken	17	2	2
LC002	21	1.567	55.5	255	90	90	16	2	3
JD003	19	1.57	46.5	258	85	85	9	2	2
LM004	19	1.67	55	250	85	85	16	2	3
HL005	20	1.672	54.5	250	85	85	12	2	2
AS006	21	1.625	57	260	85	85	16	2	2
DR007	22	1.63	58	245	70	70	10	2	2
SW008	20	1.583	52	255	70	70	16	4	3
LH009	22	1.57	55	195	85	85	11	3	3
BW010	23	1.608	56	230	75	75	8	2	3
Average	20.80	1.62	56.85	248.30	81.11	81.11	13.10	2.30	2.50
STD	1.25	0.05	7.98	22.05	6.98	6.98	3.27	0.64	0.50

2.2 Procedure

The experimental procedures were approved by the Institutional Review Board (IRB) of the University of South Florida prior to data collection. All subjects gave informed consent before participating.

2.2.1 Marker Set

The marker set came from currently used markers set in the literature and what was the most important information to gather from the study. The marker set is very close to the Plug and Gait marker set, but the Plug in Gait (VICON Motion Systems, Oxford, UK) only has lateral knees and ankles. The primary focus of the study was the motion of the knees and therefore medial knee marker was added to get more accurate motion of the knee. Medial ankle marker

was also added to the marker set, this was to accommodate the change on the foot marker set. With the heels toughing there could not be a heel marker, therefore the foot markers set had medial and lateral ankles and two toe markers, one on the first metatarsal and fifth metatarsal. This study was only looking at the lower body so the torso was defined, but not the arms. To cover the torso, markers were placed on the clavicle (CLAV), sternum (STRN), right and left shoulders (RSHO and LSHO), cervical spinal nerve 7 (C7), thoracic vertebrae 10 (T10), and for a reference marker right back (RBCK). This is consistent with the Plug and Gait markers set and some for the other marker set that were reviewed for the background, but most of them did not have a reference marker[1, 2, 4, 15]. The clavicle marker was placed on the skin by sight in the notch were the clavicles meet. The sternum marker was placed on the skin on by sight on the sternum. Both the right and left shoulder markers were placed on the acromion of the shoulder, this marker was placed on the skin or on the fabric for the subject shirt depending on the type of upper body clothing the subject was wearing. The C7 marker was placed by sight and touch on the upper neck of the subject on their skin. T10 was placed by sight and touch on the subject's clothing. With the RBCK marker just being for reference, it was placed on the subject's clothing on their right shoulder blade.

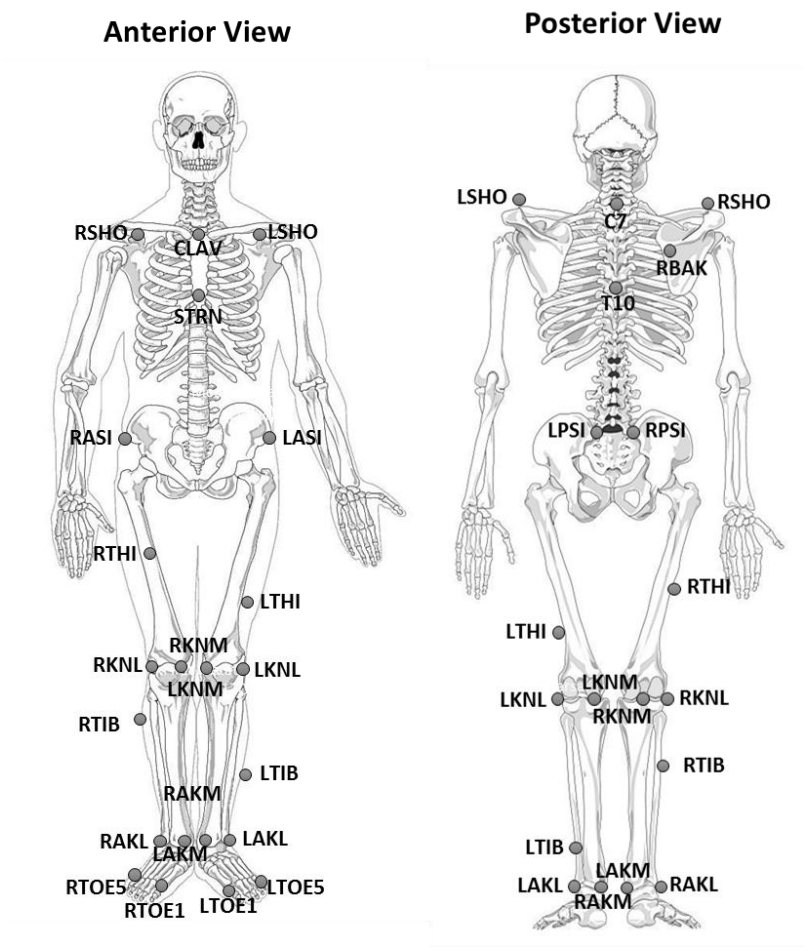

Figure 8: Dance Marker Set (Public Domain)

The next section of the subject to be marked was the pelvis. The pelvis was made with markers at the right and left anterior superior iliac spine (RASI and LASI) and the posterior superior iliac spine (RPSI and LPSI). These markers were placed by feeling for the ASIS and PSIS on the subjects. These markers where placed on a neoprene belt with loop fasteners on the back of the markers.

Table 2: Marker Set for Dance Study

Description	Markers Name
Shoulders	RSHO, LSHO
Clavicle	CLAV
Sternum	STRN
Cervical spinal nerve 7	C7
Thoracic vertebrae 10	T10
Right Back	RBAK
Anterior Superior Iliac Spine	RASI, LASI
Posterior Superior Iliac Spine	RPSI, LPSI
Thigh	RTHI, LTHI
Knee (lateral and medial)	RKNL, RKNM, LKNL, LKNM
Tibia	RTIB, LTIB
Ankle (lateral and medial)	RAKL, RAKM, LAKL, LAKM
Toe	RTOE1, LTOE5, RTOE1, LTOE5

Each leg is marked the same way, but will only be going in to detail for the right leg. For the left leg markers, just replace the “R” with an “L”. From the pelvis markers we mark the thigh. The thigh marker (RTHI) was placed on the skin in a line from the pelvis to the lateral knee, it is not placed in the middle, but on one leg the marker will be closer to the knee and the other will be closer to the pelvis. This is to provide asymmetry for the system. The next markers are the knee markers (RKNL and RKNM). They are placed on the skin of the medial and lateral knee. These markers were placed by feeling for the lateral condyle and the medial condyle. These positions were found by having the subject bend their knee back and forth in small movements to feel for the bones that did not move and this that was where the markers were placed. Then just like the thigh, the shank/ tibia marker (RTIB) was placed on the skin of the

shank on the line from the knee to the ankle with one marker close to the knee and the other marker close to the ankle, this was done to provide asymmetry for the system. The ankle markers (RAKL and RAKM) were placed on the skin of the subject of the medial and lateral malleoli.

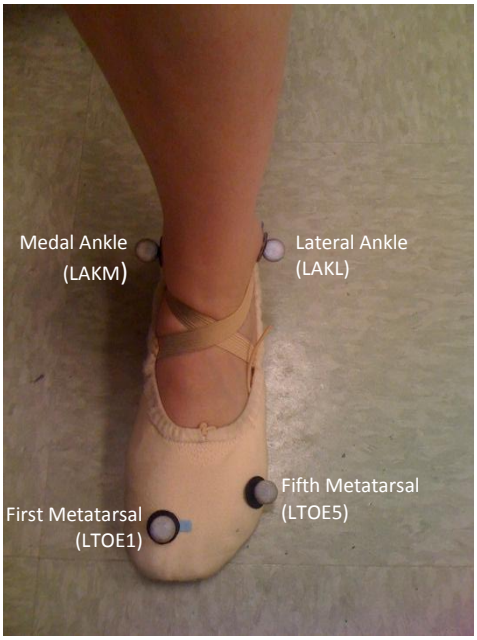

Figure 9: Picture of Foot Markers

To make the foot segment, this study used two markers on the foot. All of the literature marker sets reviewed for this study had a heel marker on the back of the foot at the heel and level with the toe marker. This can be seen in Figure 9 . Because the dances are starting out in first position, which requires the heels to be touching, this marker could not be used to make a foot segment. So to make the foot segment two toe marker were used, the first one at the first metatarsal (RTOE1) and second one at the fifth metatarsal (RTOE5). These two markers on the toes combined with the ankle markers make the foot segment for this study.

2.2.2 Calibrating VICON

All eight (8) of the cameras were arranged to cover the capture volume. This was checked by walking into the capture volume with the wand and looking at how much of the wand shows up on each of the cameras. The cameras set system was set to record at 120Hz. The cameras are checked for any reflective surface in the collection volume. Then the cameras are masked using the system by having the masking feature for about 10 seconds or until all of the white spots turn blue. Now with the cameras masked, the cameras can be calibrated. Calibration was done to tell the system were the cameras are located in 3D space. This will allow the cameras to triangulate the location of each marker in real world units. With the calibration wand turned on, one of the investigators waves the wand in the collection volume until all of the cameras are calibrated. Now with the cameras calibrated the volume is set. The lab origin is set with the static calibration of the system. For the dance study the wand in put on the corner of right force plate.

2.2.3 Marker Set in VICON

The marker was set template in VICON NEXUS (VICON Motion Systems, Oxford, UK). First a starting subject was marked up with the marker set on their body. In this case it was a member of the lab and not a real subject. To begin the new study in the VICON system, first a new research project was created in the VICON data management system. Then a subject was created and a session node was created. This process was repeated with all of the subjects for this study. It was then selected that the processing level would be set to reconstruct. To make the new markers set in VICON first a template had to be made, and then this template was attached to all the subjects in the study. Under the Subject tab the “new template file’ was selected and given the name “Nyssa Dance”. To make the new template a test subject has to be marked up will all

the markers for this study. Then the test subject stands in the middle of the data collection field for a few seconds for a static trial. The test subject stands as still as they can with their arms in a "T" stance so all markers were clearly visible to the cameras. Under the Subject Capture, the start button was pressed and the test subject holds the stance for a few seconds after the start button was pressed again to end the data collection. Then with Nexus in the "Off Line" mode the trial was reconstructed by clicking the reconstruction icon. With the markers collected and reconstructed it was time to give them names, but first segments had to be made. The first segment to be made was the Root Segment, for this study was the pelvic segment. In the Labeling Template Builder the name of the root segment was entered and clicked to create segment. Then the mouse was moved over the RASI, and left click, and then the LASI, and left click, then the RPSI, and left click, and finally the LPSI, and left click. Then the create button was clicked. This makes the segment turn yellow. This process was repeated for the torso segment, the right and left upper leg segments, right and left shank segments, and the right and left foot segments. For the torso segment the order is CLAV, STRN, C7, T10, RBAK, RSHO, and LSHO. The torso segment was independent of the pelvic segment. Next the right and left leg segments were made. This was done by linking the leg segments with the pelvic segment. First the right leg was made. The right thigh was made by linking the markers in following order: RASI, RKNL, RKNM, and RTHI. For the right shank the markers were linked the following order: RKNL, RAKL, RAKM, and RTIB. The right foot segment was made with the markers in the following order: RAKL, RAKM, RTOE1, and RTOE5. Next the left leg was made. The left thigh was made by linking the markers in following order: LASI, LKNL, LKNM, and LTHI. For the left shank the markers were linked the following order: LKNL, LAKL, LAKM, and LTIB. The left foot segment was made with the markers in the following order: LAKL, LAKM,

LTOE1, and LTOE5. Now with all the segments completed, the individual markers were named. This was done by opening the Resource panel and on the Subject tab, the Marker section was expanded to review all the makers. Each of the markers where clicked and changed to their correct corresponding marker name; for example Unlabeled0 to CLAV. This was done for all 27 markers. Also the color of right markers was changed to green and all the left markers where changed to red. But the pelvic and torso marker where changed to yellow. Now with the segments made and all of the markers named they had to be linked by joints. This was done in the Labeling Template Builder in the Link Segment dropdown box. Ball joint is selected and the root segment (pelvic) was clicked and then the segment that was to be connected to it, the Right Thigh. This was done for all of the segments: right thigh to right shank, by ball joint, and right shank to right foot by a ball joint, left thigh to left shank, by ball joint, and left shank to left foot by a ball joint. Only the pelvic to torso was not a ball joint, it was a free joint because they have no markers in common. Now with template completed it was saved so it could be applied to all of the subjects for the study. With template completed these steps do not have to be performed again.[18]

2.2.4 Adding a New Subject

For each subject in the study a VICON Skeleton was created. This was done by creating a new subject in the Data Management widow by clicking the new subject node and given it a name. For this study the subject name was their first and last initials zero and their two digit subject number, example AC001 was the first subject. Under the Resources pane on the Systems tab the “Create a new subject from a template” was clicked and then the template was selected (Nyssa Dance). Then the subject was marked up with all the markers, they moved into the Capture Volume where the subject stood in the middle with their arms out in a T stance for the

static collection. This was position was held few a seconds (about 5s). Next the system went off line and the data was reconstructed. Next the markers were labeled under the Tool panel with the Label/Edit button. Then to make the auto label, under the Tool panel in the Subject Calibration then Calibrate Labeling Model pipeline was selected and run. With this done all the segments have a cylinder between them. Then the subject was saved and ready for data collection.

2.2.5 Capturing the Data

With each of the subjects created in the Data Management window, a session was added to the subject. With the system in the Live mode the Capture panel became active. On the Trial Name field was where the name of each of the trial was recorded. If more than one trial was needed to get the correct movement then a number was added after the name of the trial. With the name of the trial in, the subject was given instructions to start the movement on the proctors command and the Start button was hit to start the trial and then hit again to end the trial.

2.2.6 Data Collection Checklist

With the informed consent read and signed by the subject. The subject did a self-directed warm-up. This was to make sure the dancers were properly warmed-up, just like they were in class to perform the movement for the study. The subject's name, height (meters), weight (kilo grams), ASIS distance (mille meters), and right and left knee distance (mille meters) where recorded on the checklist. The distances were all measured by the same person and were from one marker to the other. Then all of the markers where placed on the subject. Twenty four of the twenty seven markers where placed on the subject's skin and clothing with double sided tape. The other four markers where placed onto the subject using a neoprene strap belt with hook- and-loop markers. These belt markers were used to put on the ASIS and PSIS markers. The markers

were placed on the subject with the help of lab assistants. The markers were checked off on the checklist as the markers were placed on the subject. With the subject marked up, the VICON system was calibrated and the force plates were zeroed. Then the subject moved in the collection volume and a static trial was collected. With the static trial collected the markers were assigned in the VICON system and the auto label performed. With everything set up it was time to collect the trials data.

The subjects were given instruction on how to perform the movement from the dance instructor. The first set of trials were the tendu with a traditional closing; this was when the dancers close flat footed. They started with their right foot in first position and perform a tendu to the front three times and then stopped. Then this was all repeated with the left foot. The next trials were in third and fifth positions. For third and fifth positions the moving foot was the front most foot for the forward tendu. With all of the traditional tendu closings completed, the subjects moved on to the trials for the modified closings. The first modified closing the subjects perform was the relevé. A relevé is when the dancer stands with their legs straight and their heels off of the ground. The subjects perform the tendu and close into the relevé. This means that as they move their moving foot closer to their body they start to move into a relevé to close. The next tendu is performed with the subject straightening their leg, so they move straight into the next tendu until three tendus have been completed. All of the same trials that were done for the traditional closing were performed with the relevé closing too. The next closing technique is the plié. A plié is defined as a bend of the knee. For this study the subjects performed a demi plié, which translates to a small bend of the knee. Again the subjects were instructed to perform the tendu and as they closed, close into a plié and then not to re-straightening the leg and go right

into the next tendu. Again they performed three tendus for each trial and did them in first, third, and fifth and to the front.

2.2.7 Post Processing

With all of the trials completed the post processing starts with transferring all of the files to the same drive so the movie files will be attached to the data files. This was done because in VICON the movie files are first stored on other drives during the data collection and need to be transferred to the drive with VICON data. If this was not done, changes made to one part of the data flies would not be transferred to all of the files, for example to change the name of a trial it can only be done after the transfer has happened. With the files transferred, the High Rigidity Reconstruct and Label pipeline was run on all of the trials. This reconstructs all the trails and applied the auto label. This was done so when opening up the trials for review they are already reconstructed and labeled. With this done one of the investigators opened each of the trials individually to check the trials for missing and incorrect labeling and to fill any gaps in the maker data. Missing labels where found by using the find next unlabeled trajectory button. When an unlabeled marker was found the correct marker label was applied to that marker manually. This was done when all missed label markers where corrected manually by assigning the correct label to the marker. All phantom markers were also deleted at this time. With all of the markers marked the next step in the post processing was to fill all the gaps of missing data for each marker. This was done by running two pipelines on all of the data. The first was Fill Gaps (Woltring filtering) with a maximum gap length of 10 and the second was a Butterworth Filter (trajectory) with a cut off frequency of 6Hz. Most of the time these pipelines would fill all of the missing data for the markers, but sometimes it would fill most of the gaps but not all. Under the fill gaps section would show which trajectories (markers) need to be filled and how many. There

was the option to use a spine fill or a pattern fill. Only the pattern fill was used in this study. This was done by selecting a source trajectory (marker) to model the fill gap after the partner marker. With most of the markers having a partner marker, medial and lateral, this made it ideal. Some examples are to fill the medial knee, the lateral knee was selected. This was how any missing shoulders, ASIS, PSIS, knees, ankles, and toes were filled. If the missing markers did not have a partner and were in a line with another marker, then the marker in the same line (z plane) was used. An example of this would be the thigh marker was filled using the either the ASIS marker or the lateral knee marker. Tibia markers were filled using the lateral knee marker and clavical markers were filled using the sternum marker and vice versa. C5 and T10 markers were also used as partner markers to fill one or the other. Now with all of the data checked and saved. The c3d files were transferred to another software, Visual 3D, for analysis.

2.3 The Model

To understand how the model for this study was made, one must first understand how the model is viewed. The model is viewed in coordinate frames, like the Cartesian coordinate system. In the Cartesian system each point is defined in a plane by pair numerical coordinates or in the case of 3-dimensional three numerical coordinates. For three dimensions with x-axis and the y-axis defined, they make the z-axis by the cross product of them. For this study the "right hand rule" was used. The right hand rule is a method to visualize the coordinate frame with your hand. With your hand straight up, the thumb makes the x-axis, the last three fingers fold over to make the y-axis and then the index finger is left straight up and that makes the z-axis. Coordinate frames are used to define distances, giving an origin to a specific location, like a marker, and it gives orientations to the axis that make up the frame. For this study the global coordinate frame was where the calibration wand was laid to set the origin. For this study, it was on the corner of

the first force plate with x and y axis defined. For the model a coordinate frame was defined for each joint as explained below.[19]

A model was made in Visual 3D (C-Motion, Germantown, MD) to analyze the angles of the knee using the c3d files from VICON (VICON Motion Systems, Oxford, UK). The model was made using the CODA pelvis model. The coda pelvis uses the anatomical location of the right and left ASIS (Anterior Superior Iliac Spine) and PSIS (Posterior Superior Iliac Spine), these bony landmarks were easily found on most subjects. These landmarks can be difficult to find on an overweight subject, but this was not an issue with this study, as we are using only healthy dance students. The model made the origin of the coordinate system at the mid-point of the ASIS markers. The x-axis was from the origin to the right ASIS while the z-axis was perpendicular to the x-y plane and the y-axis was defined as the cross product of the x-axis and the z-axis. The CODA pelvis will automatically create the right and left hip joint centers [20, 21].

The upper leg model for the thigh was made using the medial knee markers. This model was made with the axis through the flexion/extension axis. This was the axis made through the lateral condyles and the medial condyles. This was the x-axis and the z-axis was made with the hip markers and y-axis was made by the cross product of these axes. The thigh marker was also defined as an extra marker.

The lower leg model for the shank was made using lateral and medial ankle markers. These markers made the x-axis and the markers at the knee made the z-axis while the y-axis was made by the cross product of these axes. The shank marker was also defined as an extra marker.

The foot was modeled with two toe markers at the first and fifth metatarsals and the lateral and medial ankle markers. The heel marker could not be used because the dancers were performing first position. In first position the heels are touching each other, so if a heel marker was used the dancer could not perform a true first position. Because the toes and ankle are not in the same plane the foot in the model tiled down like the foot was in extension. To correct for this the toe markers where projected up to the plane of the ankles. This was done by making a plane at the ankles called RXY and LXY. These planes were made with landmarks (dummy markers) RX, RY, LX, and LY. The projection for the maker RTOE1 was done with a starting point at RAJC (the joint center for the right ankle) and the ending point at RX, with the lateral projection at RY and it was projected from RTOE1. These same steps were followed for LTOE1, but using LAJC, LX, LY, and LTOE1. And for the RTOE5 the starting point at RAJC (the joint center for the right ankle) and the ending point at RX, with the lateral projection at RY and it was projected from RTOE5. It was the same with LTOE5, by replacing with LAJC, LX, LY, and LTOE5.

Now with the model made, it creates what Visual 3D calls a CMO file. From this one CMO file it made three CMO files. Three CMO files were made so the data could be split up into first position data, third position data, and fifth position data. This was done because with each the subject performing the tradition, relevé, and plié closing they are their own control. And the interest of this thesis was to look at how the knee angle changes in the different closing. One can also look at how it changes in the different closing position (first, third, and fifth), but that was not in the scope of this thesis.

2.3.1 Inputting Motion Files

Now with the model made, it was time to apply it to the motion files from the VICON motion capture system. To create the model for each of the subjects, first the static calibration file from VICON had to be added. This was done by selecting the create button and selecting create hybrid model from C3D file. Then the file comes up with the name from VICON system. The same calibration file name was used in both VICON and Visual 3D. From here the create button was selected. Under the Models tab, the Subject Data/ Metrics were opened. In this section the individual subjects height in meters and weight in kilograms was add. Doing this makes the model accurate to each of the subjects. With the individual model made for that subject the motion file can be applied to the model. All of the motion files for that subject are opened in Visual 3D and "Insert new files into current workspace" was selected. Then the assign model to motion data dialog box opens and the appropriate motion files are checked for the appropriate static trial. To check that files were not assigned to another model the investigator could check old files that were already assigned to a model to make sure they would not be assigned to the new model. This was done because all of the trials were named the same for each subject. Now with the model made for each of the subjects, the pipelines were run to find the knee angles as the dancers move though each of the different closings.

2.3.2 Kinematic Model Calculations

The pipeline in Visual 3D that computes kinematic and kinetic data is called "compute model based data". In this pipeline the calculation for the knee angles are done. For the right knee the name is RKNEE and JOINT_ANGLE was selected with none of the coordinates negated. Then the segments for the calculation are selected. The segment was right shank and the

reference segment was the right thigh. This means the angle that was calculated showed the angle of the shank was moving with respect to the thigh. The order of the calculation was X-axis, Y-axis, and then the Z-axis. The same was done to make a pipeline for the left knee. From these pipelines graphs for the x-direction, the y-direction and the z-direction were made. The x-direction represents the flexion and extension of the knee with a normal flexion of 140˚ and 5˚ to 10 of extension. The y-direction represents the abduction and adduction of the knee, this angle is also called the varus and valgus angles of the knee, and are normal a 170˚ and 175˚, so is only a range of 5˚. And finally the z-direction represents the rotation of the knee with the normal range for rotation with a straight leg was 10˚[13].

The math for this was done within the program, but it used the Euler Angles with the rotational order of XYZ selected. This means that the order of the matrixes are the rotation about X time the rotation about Y, then this matrix is times by the rotation about Z [22]. The rotational matrixes for the X, Y, and Z axis are as follows:

$$R_X(\gamma) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\gamma & -s\gamma \\ 0 & s\gamma & c\gamma \end{bmatrix} \quad \text{Equation 1}$$

$$R_Y(\beta) = \begin{bmatrix} c\beta & 0 & s\beta \\ 0 & 1 & 0 \\ -s\beta & 0 & c\beta \end{bmatrix} \quad \text{Equation 2}$$

$$R_Z(\alpha) = \begin{bmatrix} c\alpha & -s\alpha & 0 \\ s\alpha & c\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \text{Equation 3}$$

where c=cosine and s=sin. Then the rotation matrix is

$$R_{XYZ}(\gamma, \beta, \alpha) = R_X(\gamma)R_Y(\beta)R_Z(\alpha) \quad \text{Equation 4}$$

$$R_{xyz} = \begin{bmatrix} c\alpha c\beta & -c\beta s\alpha & s\beta \\ c\gamma s\alpha + c\alpha c\gamma s\beta & c\alpha c\gamma - s\alpha s\beta s\gamma & -c\beta s\gamma \\ s\alpha s\beta - c\alpha c\gamma s\beta & c\alpha s\gamma + c\gamma s\alpha s\beta & c\beta c\gamma \end{bmatrix} \quad \text{Equation 5}$$

where c=cosine and s=sin

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \quad \text{Equation 6}$$

then for to find the knee angles of flexion, abduction, and rotation

$$Flexion = \gamma = Atan2(r_{32}/c\beta\,, r_{33}/c\beta) \quad \text{Equation 7}$$

$$Abduction = \beta = Atan2(-r_{31}, \sqrt{r_{11}^2 r_{21}^2}) \quad \text{Equation 8}$$

$$Rotation = \alpha = Atan2(r_{21}/c\beta\,, r_{11}/c\beta) \quad \text{Equation 9}$$

2.3.3 Splitting the Trials

As mentioned earlier, each of the subjects performed three tendus during each trial. With wanting to look at each closing the trial had to be split up into the individual movements. This allowed for the statistics to be performed on the data. The Visual 3D software has the ability to split the data by creating events; the question was which one was most efficient and accurate of all of the trials.

The first way that was tried was to assign instant events at a different frame and to find the maximum and minimum in-between these instant events. The instant events were placed on the slop of the line as the foot moved forward. The thought behind this was that as long as that event fell along the slop in the other trials it would still work. This worked well for the trial that was the set up was done on. But when it was applied to all of the other similar trials, it did not work as well. This was because all of the trials were different in length. For example some of the trials were over 15s whereas others were only about 7s.

The next method used was to find the globe maximum and from there use the threshold event to create an offset of the maximum. The globe maximum was found using a metric

pipeline. The threshold was set to when the TOE1 marker exceeded the percentages of the maximum then it would create an event. After trying different thresholds it was found that four present of the globe maximum had the most successes of finding the start of the movement without having to manually add the events. This method worked better than the first method that was tried. It successfully created the events in the other trials. To get the last trial one more start need to be created (Equation 10). For others it did not work as well and the threshold value had to be adjusted. By looking at the trial, it was noticed that not all of the subjects moved their foot back to the same place throughout the trial. From these events the reporting feature of Visual 3D was used to make the graphs so movement could be normalized. With all of the trials taking a different amount of time the only way to compare the movement was to normalize it. The normalization was in percentage of tendu cycle.

$$Start[4] = Start[3] + (Start[3] - Start[2]) \qquad \text{Equation 10}$$

2.3.4 Reporting the Data

The data from all of the trials was reported using the Report feature of Visual 3D. This was done because all of the data had to be normalized for the length of the tendu. The tendus were normalized using the events that were described in the above section. The data was graphed in the report section, and this was where the data was normalized. The normalizing was done in the time axis of the graph. The data was graphed from the Start of one movement to the Start of the next movement. This allows for the complete movement to be graphed with no data being cut. Each of the components was graphed. The flexion or x component was on one graph and the adduction or the y component was on the next and the rotation or the z component was on the last graph. On all of the graphs, the individual data was graphed along with the mean of the data and the standard deviation. The data was normalized in the graphs in Visual 3D. Next the

normalized data was exported out of Visual 3D to a text file that then could be opened in Excel. With the normalized data now in Excel the graphs for the subjects could be made. This was done because Excel gives the investigator more ability to edit the visual look of the data than Visual 3D does. Because of the coordinate frame set in Visual 3D, the left knee angles for abduction and adduction along with internal and external rotation of the knee required the coordinate axis to be reversed. This was because if the knee is moving away from the body on both the left and right knees then it will look like abduction for the right knee but adduction for the left knee, because it was moving in the negative even though it was really abduction.

2.4 Statistics

Statistics was performed on the range of motion data for all of the trials. The range of motion was calculated inside of the Visual 3D software using three different pipelines. Two of the pipelines calculated the minimum and maximum angle for each of the trial events. From the minimum and maximum the difference was found and this was the range of motion for each of the trials (Equation 11), the trial was from start to finish of each tendu. With the range of motion calculated the numbers were recorded and placed in to the Statistical Software Package of Social Sciences version 20 (SPSS Inc., Chicago, Il, USA) for the repeated measures analysis of variance (ANOVA) statistical analysis. The SPSS software was used on each of the subjects' range of motion for first, third, and fifth position. If there was no data for one of the subjects, then SPSS software was given a value that would represent a missing number. For all of the trials the number "99" was used as the variable for the missing number. It was not expected for any of the subjects to a range of motion of 99 degrees.

$$ROM = Knee\ Angle_{max} - Knee\ Angle_{min} \qquad \text{Equation 11}$$

The statistical analysis used in this study was the repeated measure analysis of variance. A repeated measure is "an independent variable for which subjects act as their own control."[23]. This is also called a within-subject design because the analysis of variance can account for the measurement of the same individual on multiple occasions[23]. With using the subjects as their own control, the difference within the group of subjects was not seen. So the difference seen within the group would show only how the subjects performed their closings. The control for this study was the traditional closing, since that was the only way the closing was taught to the dancers. The repeated measure looks at the sum of squares total (Equation 12). This was done by looking at the sum of squares for the subject, residual, and between groups. Then the F-ration was the variability between and then dived by the variability of the residual (Equation 13).

$$SS_{Total} = SS_{Subject} + SS_{Resiual} + SS_{Between} \quad \text{Equation 12}$$

$$F = {S^2_{Between}}/{S^2_{Resiual}} \quad \text{Equation 13}$$

The SPSS software produces many outputs, the outputs that were reviewed were the descriptive statistics, Mauchly's Test of Sphericity, Test of Within Subjects Effects (which included power), and the Pairwise Comparison. The first of these that was reviewed was the Mauchly's Test of Sphericity. Sphericity is where all of variances are equal in the data set. Part of running a repeated measure ANOVA is the assumption of sphericity and this is where the Mauchly's test of sphericity comes in. By looking at the significance of the test it can be seen if there needs to be an adjustment to the p value. If the test shows significance then an adjustment will need to be made. There are two adjustments that SPSS performs, first is Greenhouse-Geisser correction and the second it Huynh-Feldt correction. It there was significance with Greenhouse-Geisser, then the correction that was used. When Greenhouse-Geisser does not result in a

significance then the Huynh-Feldt correction was used if it does result in a significant.[23] Only the Greenhouse-Geisser correction was used in this study.

The Mauchly's test of sphericity was read by looking at the significance column to read if the significance was 0.05. If the significant was above 0.05, than there was no significance which means that there was sphericity within the data and that the p-value for the "Sphericity Assumed" can be read as the significance. If the number was 0.05 and below then there was significance for the Mauchly's test and the Greenhouse-Geisser correction was applied to the data. With the sphericity test completed, the p-value was read for the Test of Within Subjects Effects table. After the overall significances of the data were reviewed, the next step was to review the Pairwise Comparisons with a confidence interval adjustment of Least Significant Difference (LSD). For the pairwise comparison, the three dance movements were compared to each other in pairs. The pairs were traditional to plié, plié to relevé, and relevé to traditional.

2.5 Anecdotal Data

Part of the data that the VICON system collected was the video from the two Bonita cameras. The Bonita cameras where set up to capture the side and front view of the dancers. They are calibrated with the inferred cameras so that the stick figure created by the VICON cameras could be over laid on the Bonita's. This feature allows for the ability to watch the data from the VICON cameras and a normal video feed at the same time. A physical therapist from USF School of Physical Therapy & Rehabilitation Sciences was consulted and the videos of the subjects were reviewed with the lead student and dance professor.

CHAPTER 3: RESULTS

3.1 First Position

The section of the data to be looked at was the tendu closing to first position in the traditional, relevé and plié movements. The first position in ballet is when the dancers feet are turned out at 180˚ to make a straight line from one foot to the next and the heels are touching. All of the data in this section is of the average of the three trials that were collected.

3.1.1 First Position Right Knee

The following graphs represent the angles of the right knee in first position. The graphs are grouped into flexion/extension, adduction/abduction, and rotation to show closings with the traditional, plié, and relevé closings.

Table 3: First Position Right Knee Flexion/Extension

First Right			
Flexion/Extension			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Significant
Plié	Significant	na	Significant
Relevé	Significant	Significant	Na

Significant is $p<0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

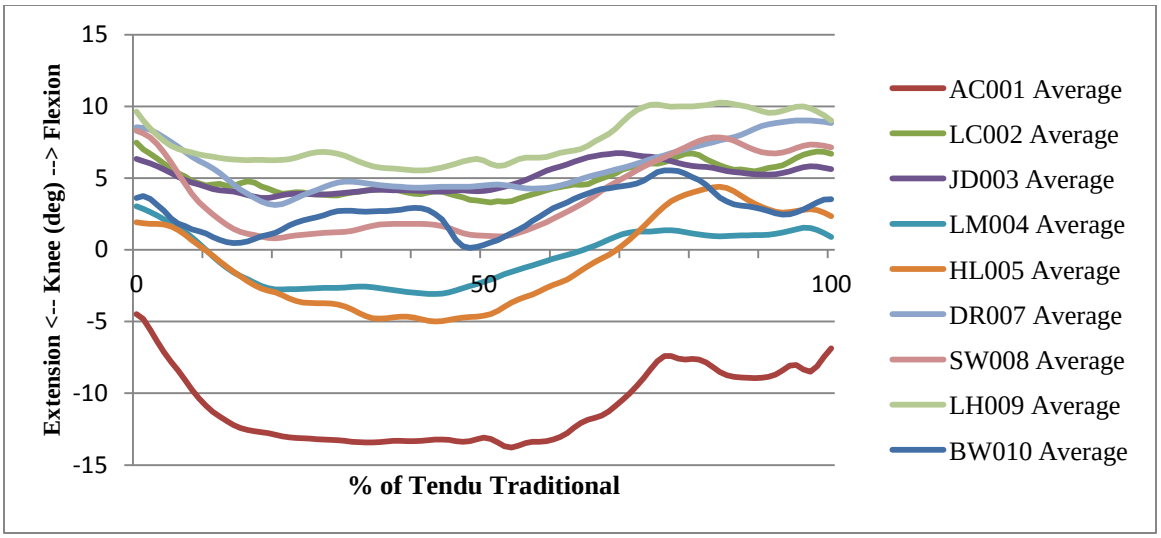

Figure 10: First Position Average Right Knee Flexion with Traditional

In Figure 10 shows the averaged of three trials for each subject performing a front tendu with the right foot. The graph is of the flexion angle, which is the angle between the shank and the thigh. This graph shows the traditional closing with is flat footed. It can also be seen that subject AC001 is in hyperextension throughout the movement. The average range of motion for all of the subjects is 6.9˚ and a standard deviation of 2.2˚.

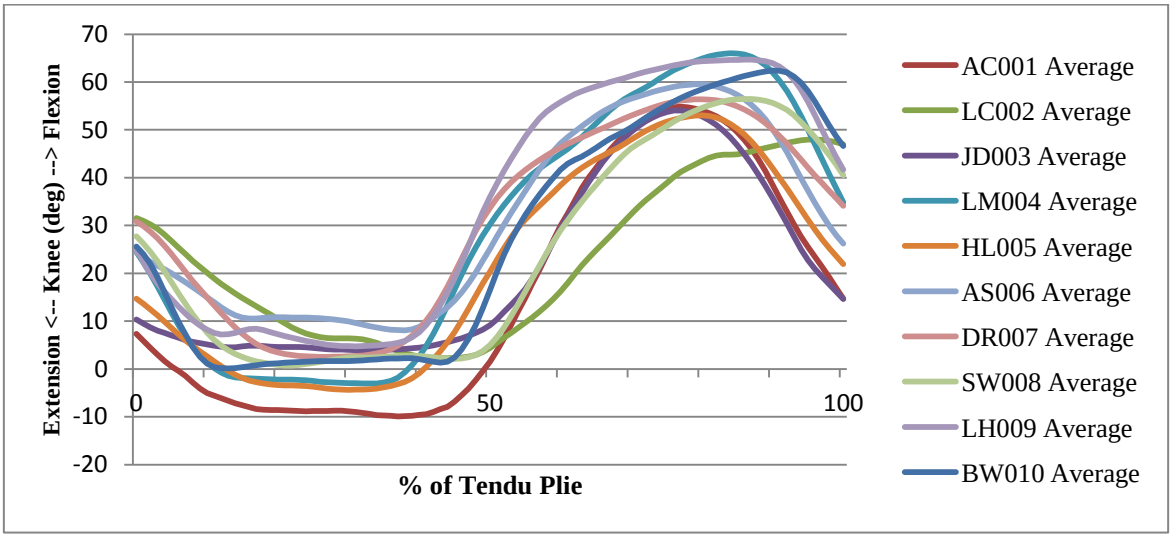

Figure 11: First Position Average Right Knee Flexion with Plié Closing

In Figure 11 shows the plié closing for first position in the flexion axis. This was the axis with the greatest ranges of motion because the knees are bending to perform the plié. The average range of motion for all of the subjects is 58.2˚ and a standard deviation of 7.2˚.

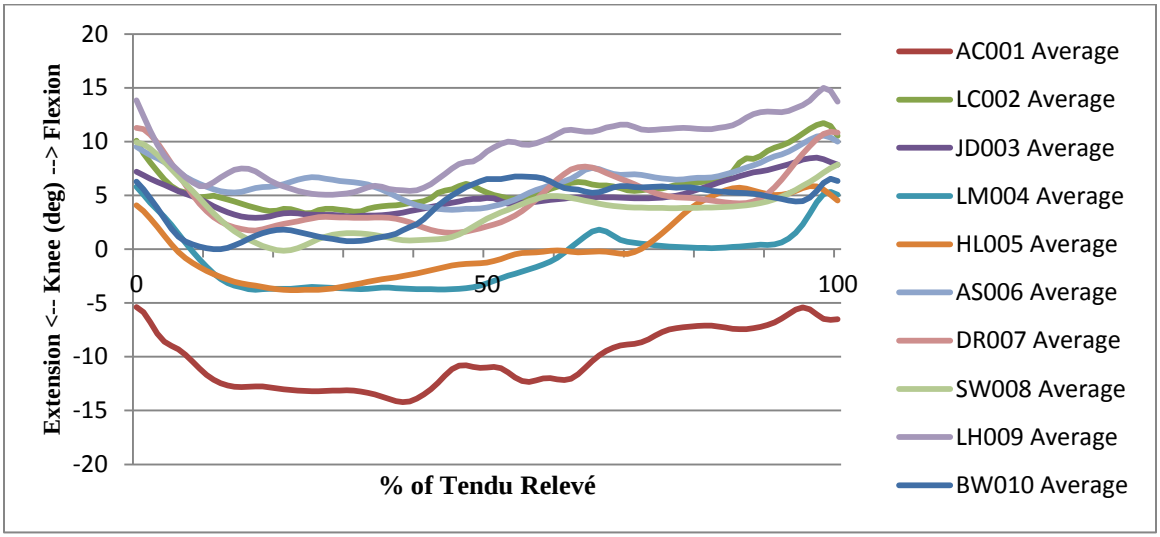

Figure 12: First Position Average Right Knee Flexion with Relevé Closing

In Figure 12 shows the flexion angles with the relevé closing in first position. This is when the dancers come up on their toes with straight legs. Just like in Figure 10 subject AC001 is in full hyperextension. The average range of motion for all of the subjects is 9.7˚ and a standard deviation of 1.8˚.

Table 4: First Position Right Knee Abduction

First Right			
Abduction/Adduction			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

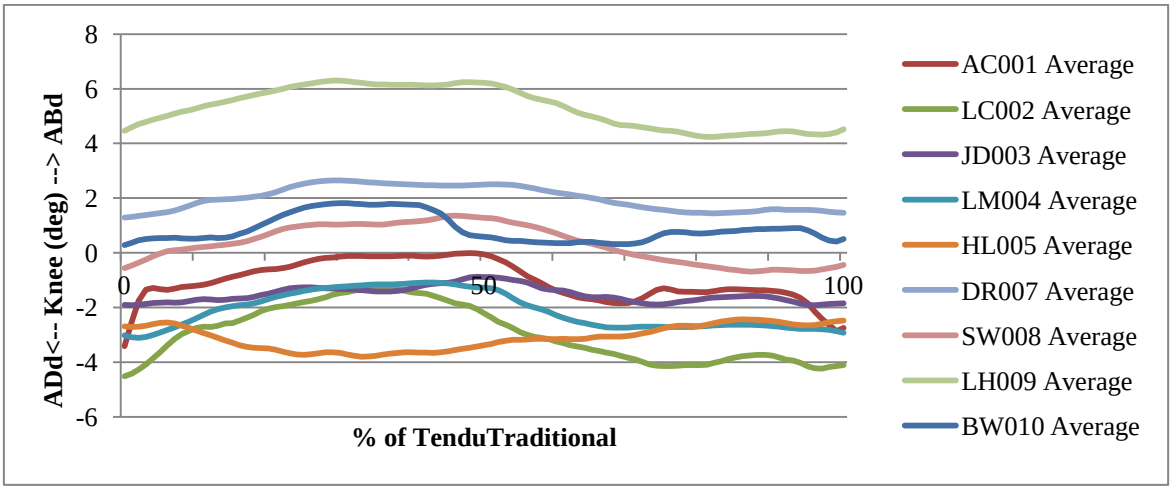

Figure 13: First Position Average Right Knee Abduction with Tradition Closing

In Figure 13 shows the graph for the traditional closing in the adduction axis. It can be seen that the angles in this axis are much smaller than that of the flexion axis. This is to be expected because the normal range of motion for this knee angle is 5˚[13]. The average range of motion for all of the subject is 2.3˚ and a standard deviation of 0.8˚.

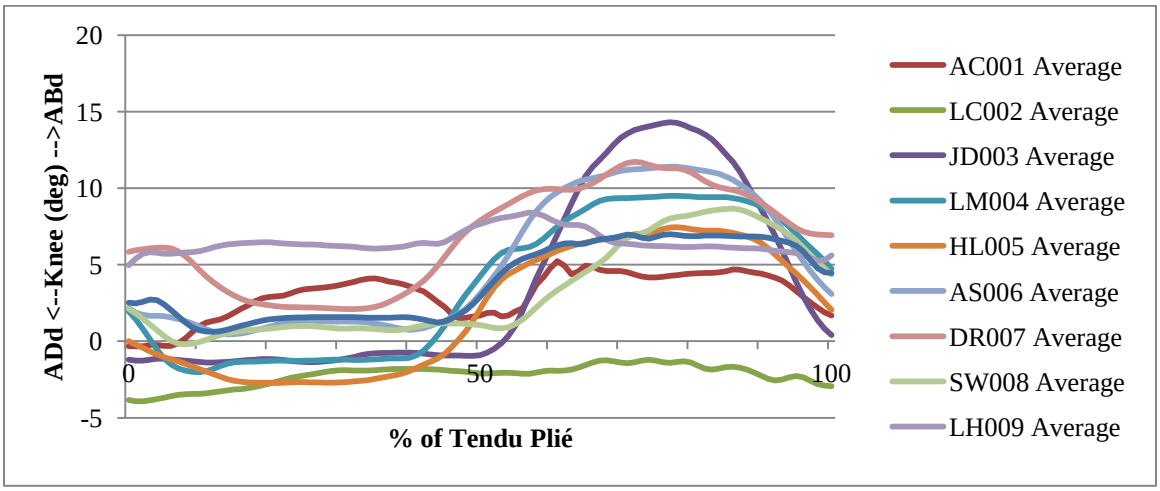

Figure 14: First Position Average Right Knee Abduction with Plié Closing

In Figure 14 shows the graph of the plié closing in the adduction axis. The average range of motion for all of the subjects for the plié closing in 8.9˚ and a standard deviation of 4.05˚, this is slightly larger than what is considered the normal range of motion for the knee for this knee angle.

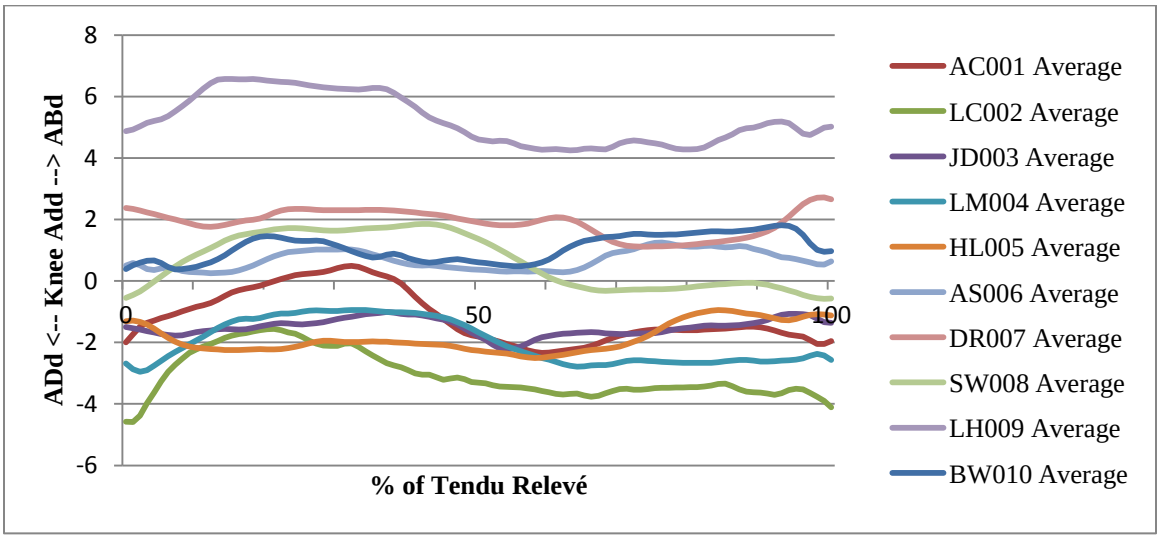

Figure 15: First Position Average Right Knee Abduction with Relevé Closing

In Figure 15 shows the graph of the relevé closing of the adduction axis. The relevé closing had a smaller range of motion average for all of the subjects of 2.3˚ and a standard deviation of 0.7˚; this is more in line with what is the normal range of motion for the knee and the same as the traditional closing.

Table 5: First Position Right Knee Rotation

First Right			
Rotation			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

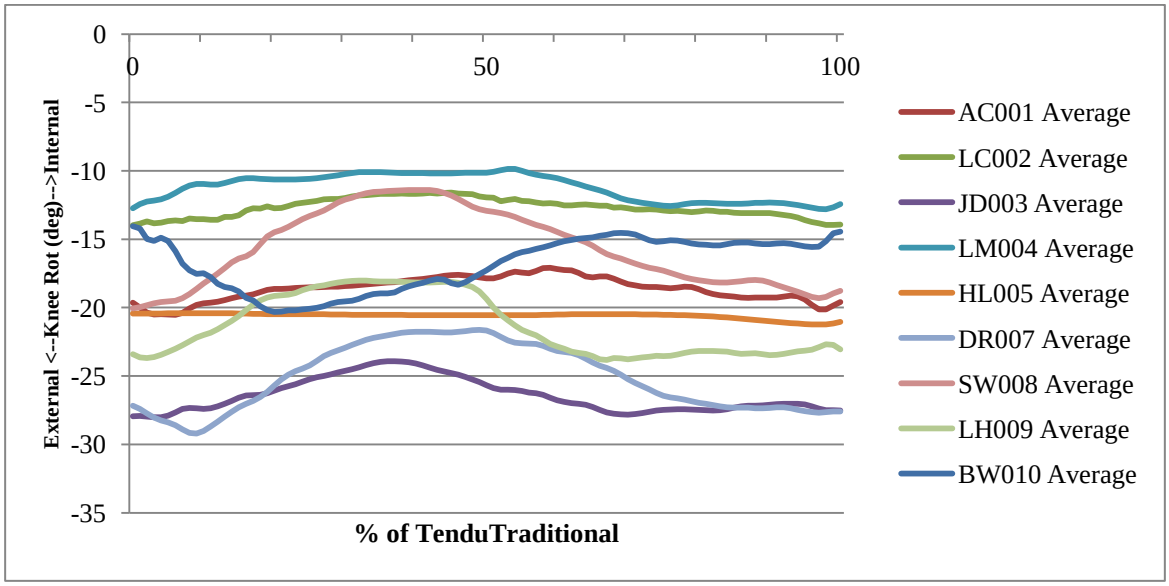

Figure 16: First Position Average Right Knee Rotation with Traditional Closing

In Figure 16 shows the graph rotation of the right knee for the traditional closing. The rotation of the knee is about the z-axis of the leg as defined in the model section. The normal range of motion for the rotation of the knee in 10˚ [13]. The average knee rotation for all of the subjects for the traditional was closing in 5.3˚ and a standard deviation of 2.4˚. This is well in the normal range.

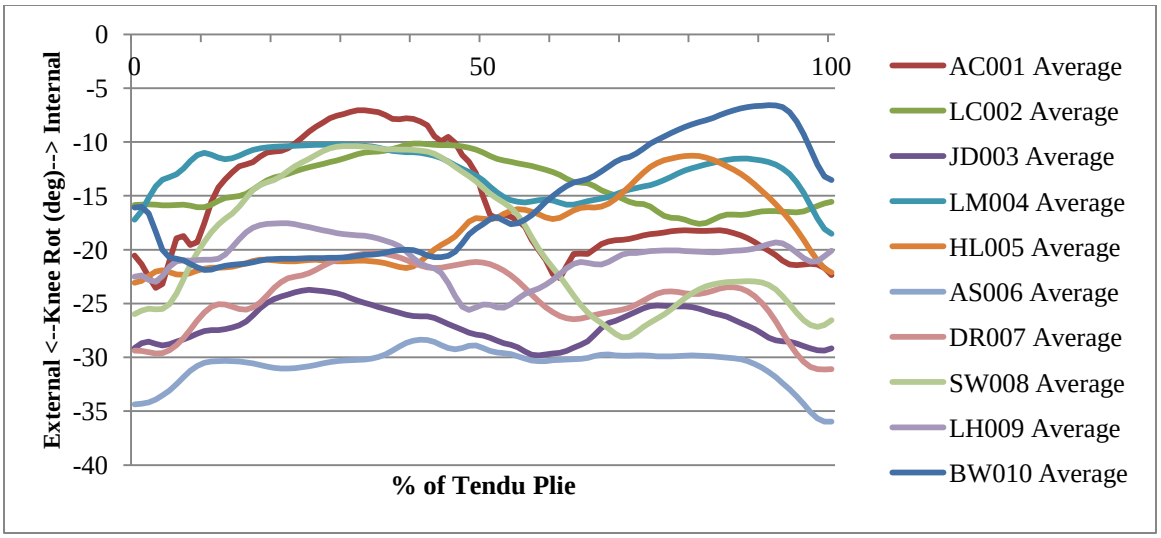

Figure 17: First Position Average Right Knee Rotation with Plié Closing

In Figure 17 shows the graph knee rotation for the right knee with the plié closing. The average of all of the subject range of motion for the plié closing is 12.4˚ and a standard deviation of 4.7˚.

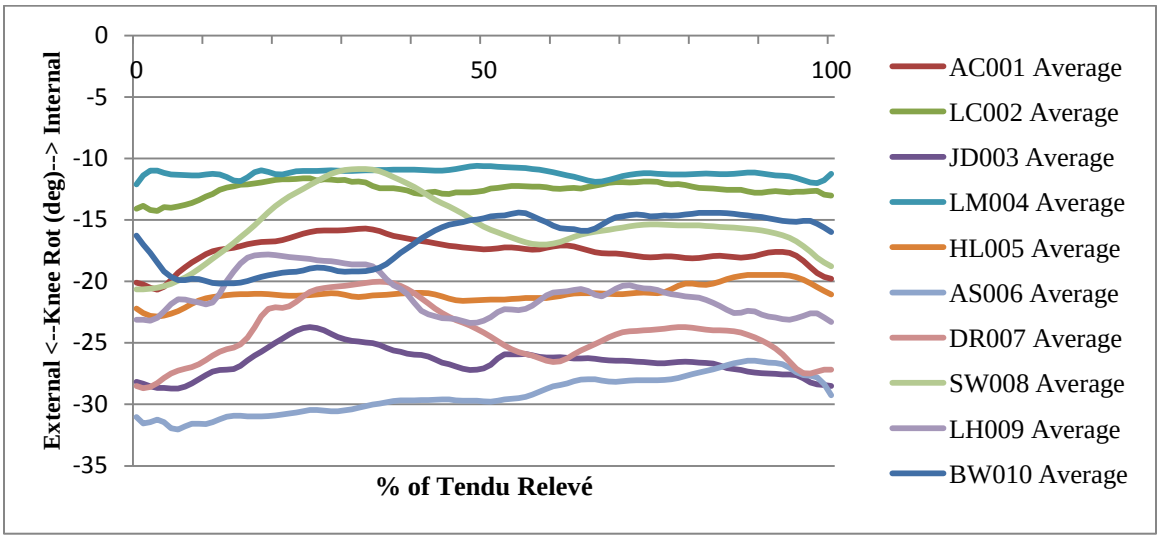

Figure 18: First Position Average Right Knee Rotation with Relevé Closing

In Figure 18 shows the graph of the rotation of the right knee with the relevé closing. The average range of motion for all of the subjects was 6.1˚ and a standard deviation of 2.8˚. This is

well within the normal range of motion for the knee in z-axis, but slightly higher than that of the traditional closing.

3.1.2 First Position Left Knee

The following graphs represent the angles of the left knee in first position. The graphs are grouped into flexion/extension, adduction/abduction, and rotation to show closings with the traditional, plié, and relevé closings.

Table 6: First Position Left Knee Flexion

First Left			
Flexion/Extension			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Significant
Plié	Significant	na	Significant
Relevé	Significant	Significant	na

Significant $p<0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

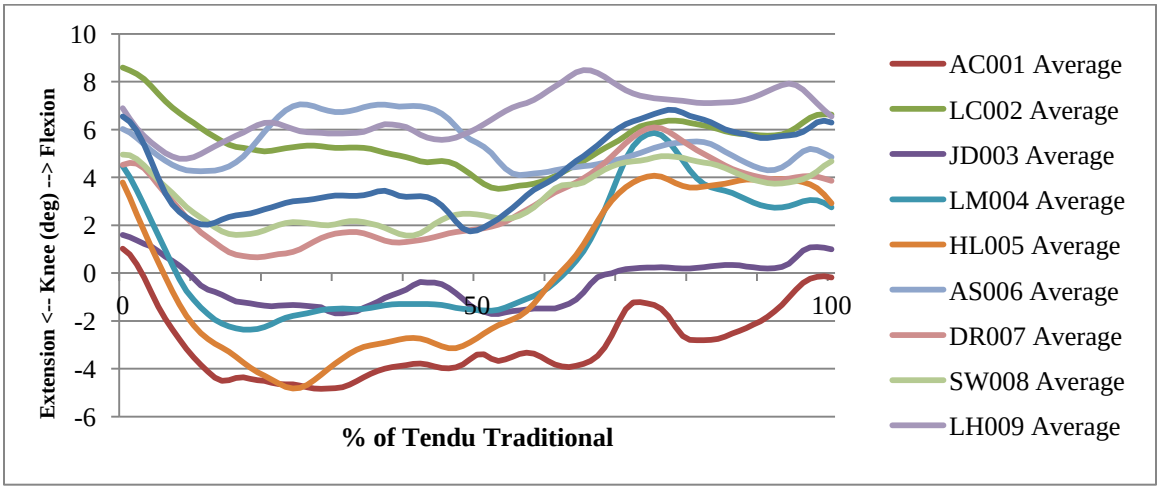

Figure 19: First Position Average Left Knee Flexion with Traditional Closing

In Figure 19 shows the graph of flexion/extension of the left knee with the traditional closing. Just like in the right knee flexion (see Figure 10) subject AC001 is performs the tendu in full extension, but less. The average range of motion of all of the subjects is 6.1˚ and a standard deviation of 2.3˚.

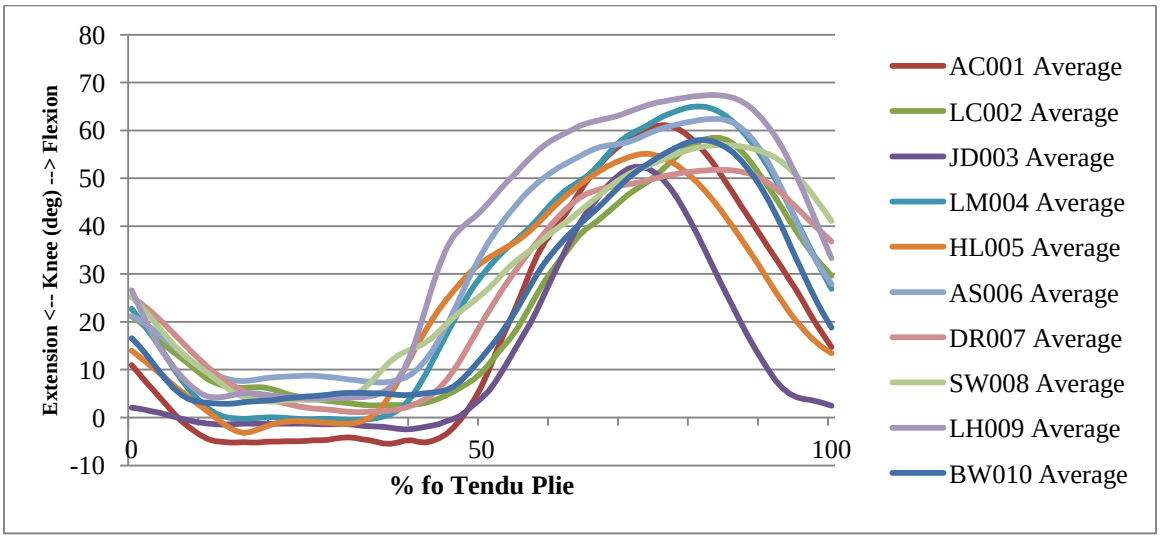

Figure 20: First Position Average Left Knee Flexion with Plié Closing

In Figure 20 shows the graph of the flexion/extension for the left knee in first position with the plié closing. The average range of motion for all of the subjects for the plié closing is 58.8˚ and a standard deviation of 5.4˚. This is almost the same as the range of motion for the right knee.

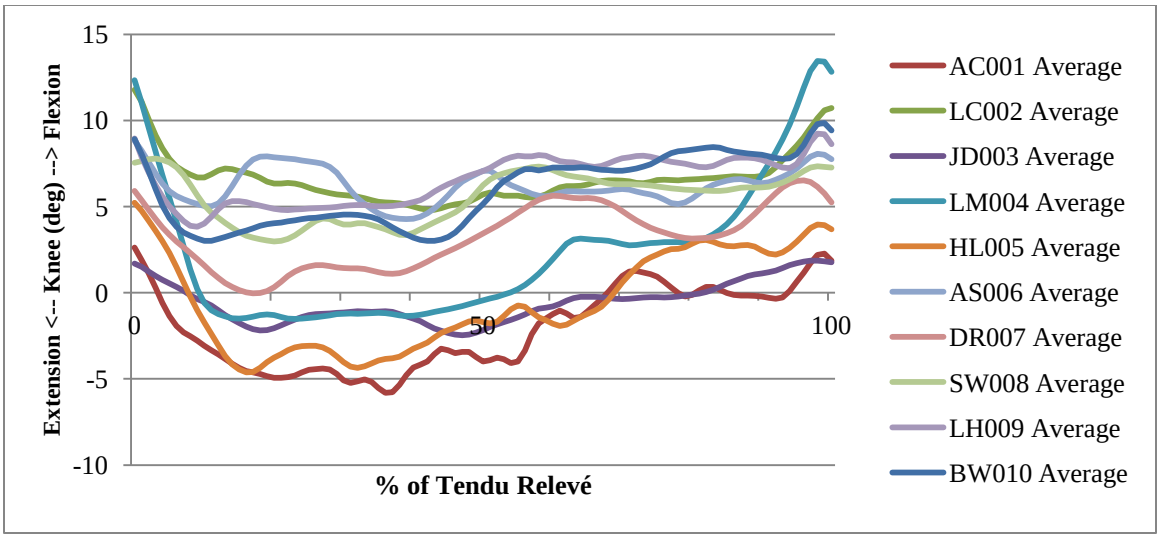

Figure 21: First Position Average Left Knee Flexion with Relevé Closing

The Figure 21 shows the graph of flexion/extension of the left knee for the relevé closing. The average range of motion for all of the subjects is 8.5˚ and a standard deviation of 3.3˚. This is smaller than the right knee, but 2˚ less than the traditional closing for the left leg.

Table 7: First Position Left Knee Abduction

First Left			
Abduction/Adduction			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

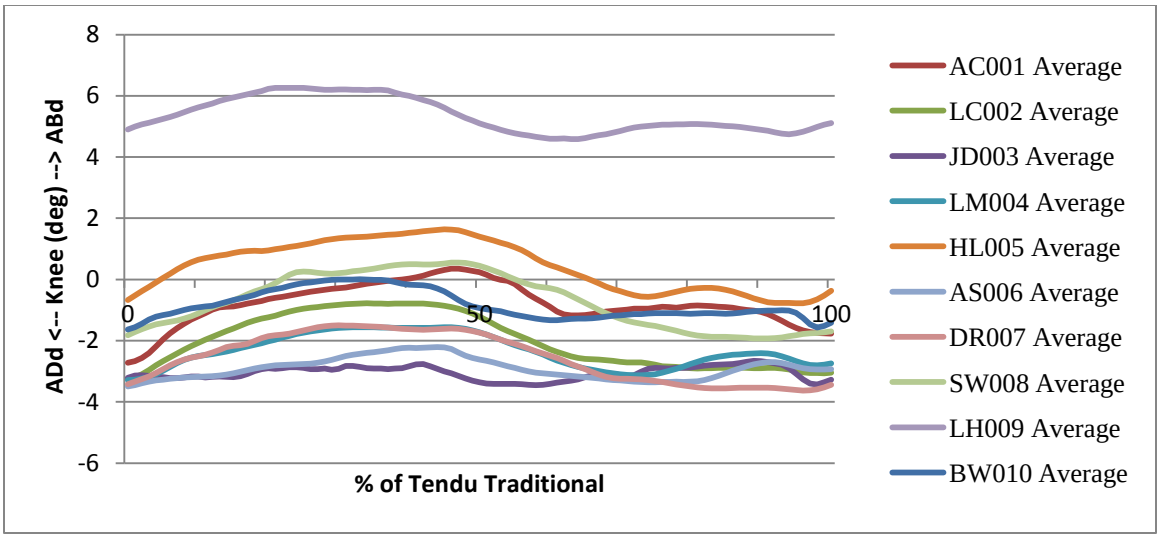

Figure 22: First Position Average Left Knee Abduction with Traditional Closing

The Figure 22 shows the graph of adduction/abduction of the left knee with the traditional closing. Subject LH009 has an abduction angle that is different than all the other subjects, but only in the left knee and not the right knee. The average range of motion for all of the subjects is 2.2˚ and a standard deviation of 0.7˚. This is right in the middle of the normal range of motion for a normal person.

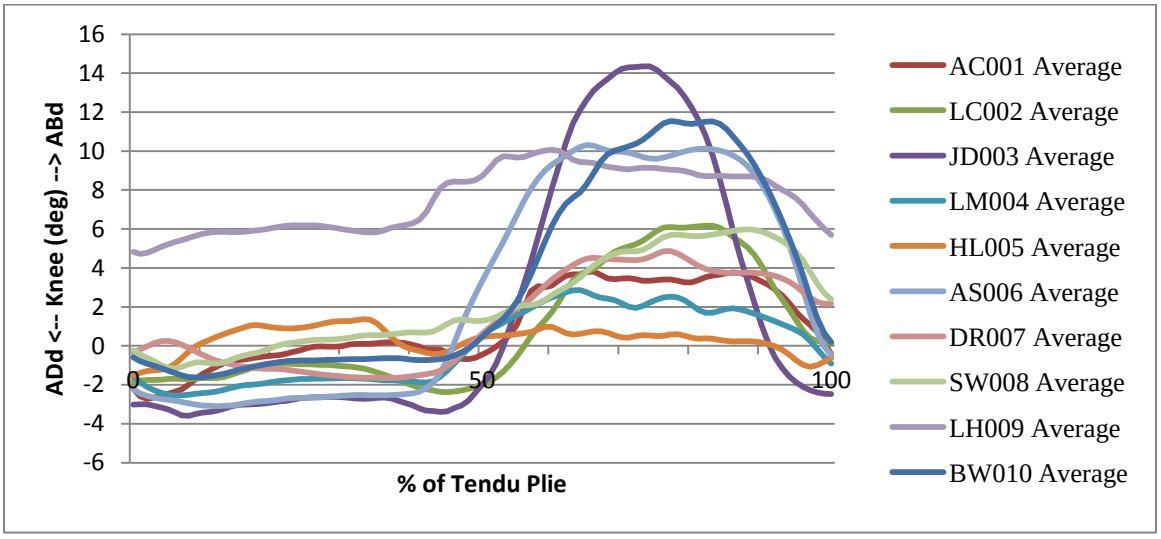

Figure 23: First Position Average Left Knee Abduction with Plié Closing

The Figure 23 shows the graph of adduction/abduction of the left knee with the plié closing. About half of the subjects have a lager range of motion for the plié closing while the others have a smaller range of motion. The average range of motion for all of the subjects is 9.3˚ and a standard deviation of 4.5˚. This is above the normal range of motion for adduction/abduction by 4˚.

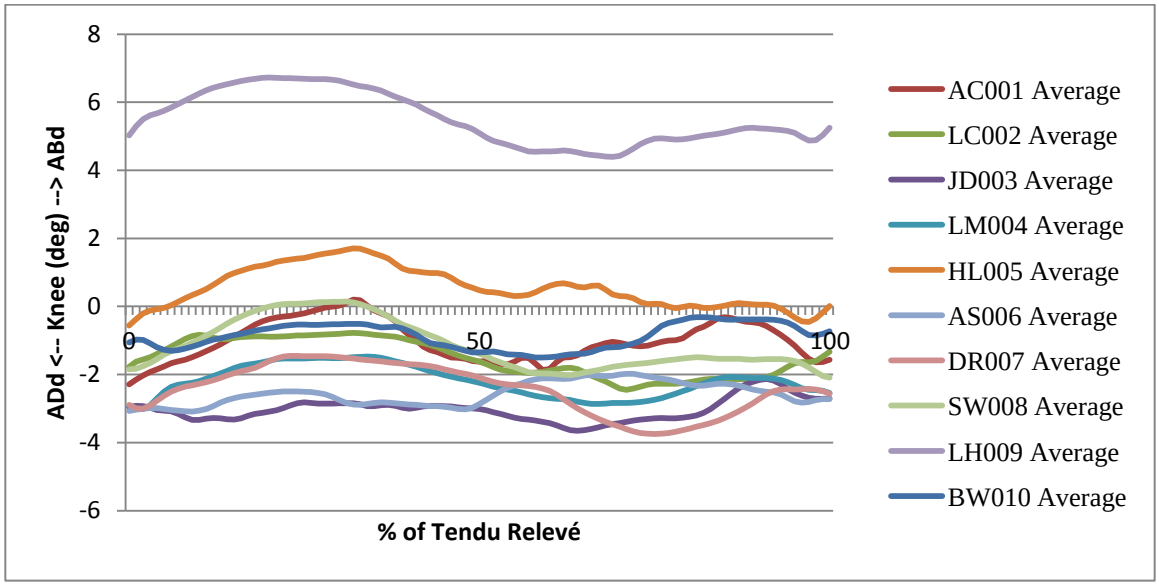

Figure 24: First Position Average Left Knee Abduction with Relevé Closing

The Figure 24 shows the graph of the adduction/abduction of the left knee with the relevé closing. Just like in the traditional closing subject LH009 has more adduction than the rest of the subjects. The average range of motion for all of the subjects is 2.1˚ and a standard deviation of 0.5˚. This is well within the normal range and the same as the traditional closing.

Table 8: First Position Left Knee Rotation

First Left			
Rotation			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq 0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

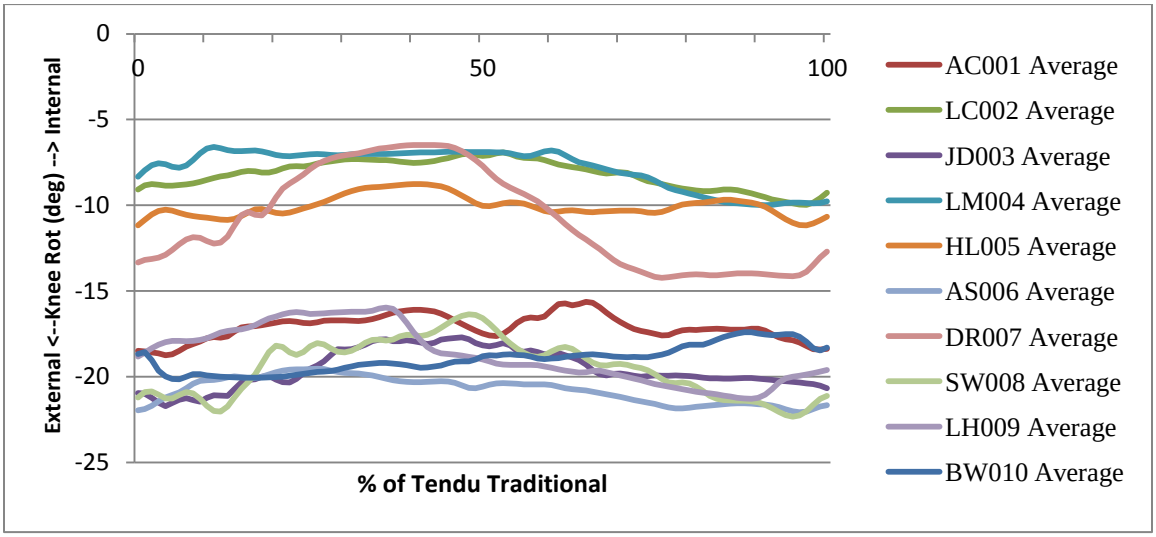

Figure 25: First Position Average Left Knee Rotation with Traditional Closing

The Figure 25 shows the graph of the left knee rotation with the traditional closing. The average range of motion for all of the subjects is 4.9˚ and a standard deviation of 1.9˚. This is well within the normal range of motion for the knee in rotation.

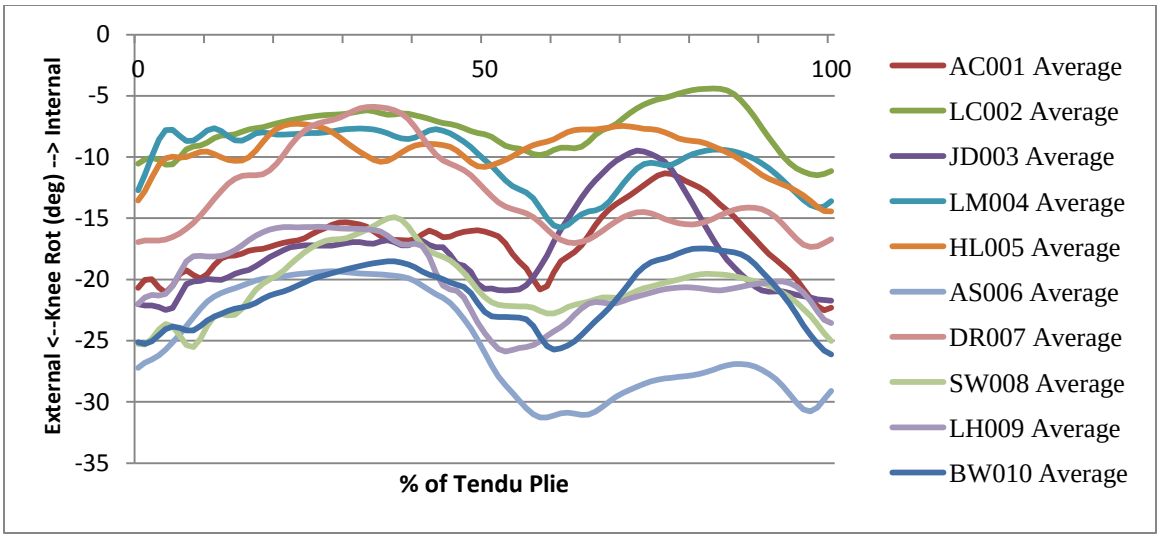

Figure 26: First Position Average Left Knee Rotation with Plié Closing

The Figure 26 shows the graph of the left knee rotation with the plié closing. The average range of motion for all of the subjects is 11.6˚ and a standard deviation of 2.03˚.

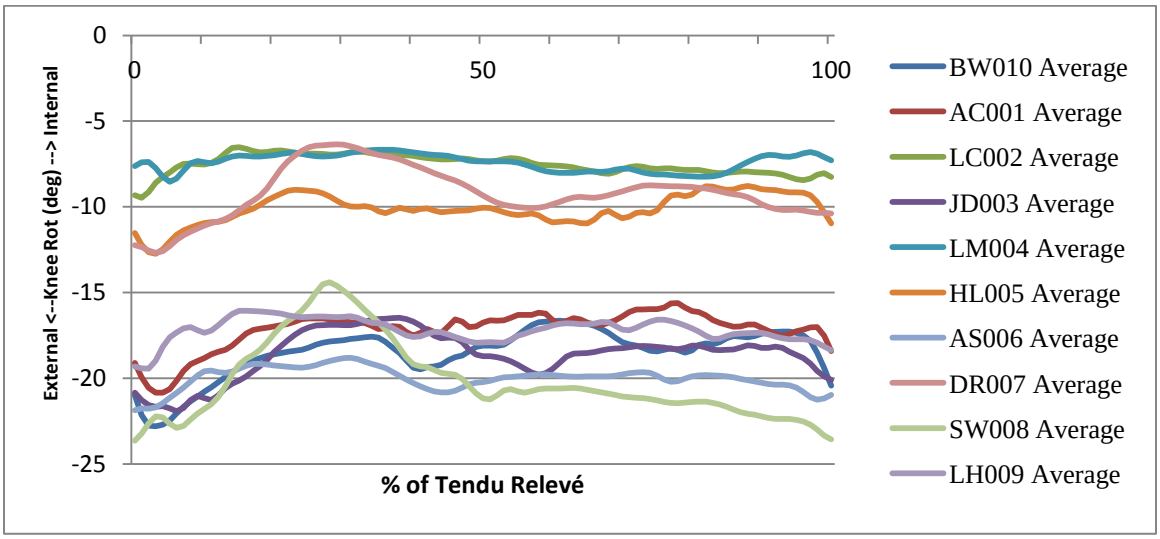

Figure 27: First Position Average Left Knee Rotation with Relevé Closing

The Figure 27 shows the graph of the rotation of the left knee with the relevé closing. The average range of motion of all of the subjects is 5.5˚ and a standard deviation of 2.5˚. This is well within the normal range.

3.2 Third Position

Third position is when the dancers stand with their feet turned out at 180˚ just like in first position, but this time their feet cross. For third position the feet are crossed with the heel of one foot at the middle of the other foot.

3.2.1 Third Position Right Knee

The following graphs represent the angles of the right knee in third position. The graphs are grouped into flexion/extension, adduction/abduction, and rotation to show closings with the traditional, plié, and relevé closings.

Table 9: Third Position Right Knee

Third Right			
Flexion/Extension			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Significant
Plié	Significant	na	Significant
Relevé	Significant	Significant	na

Significant $p<0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

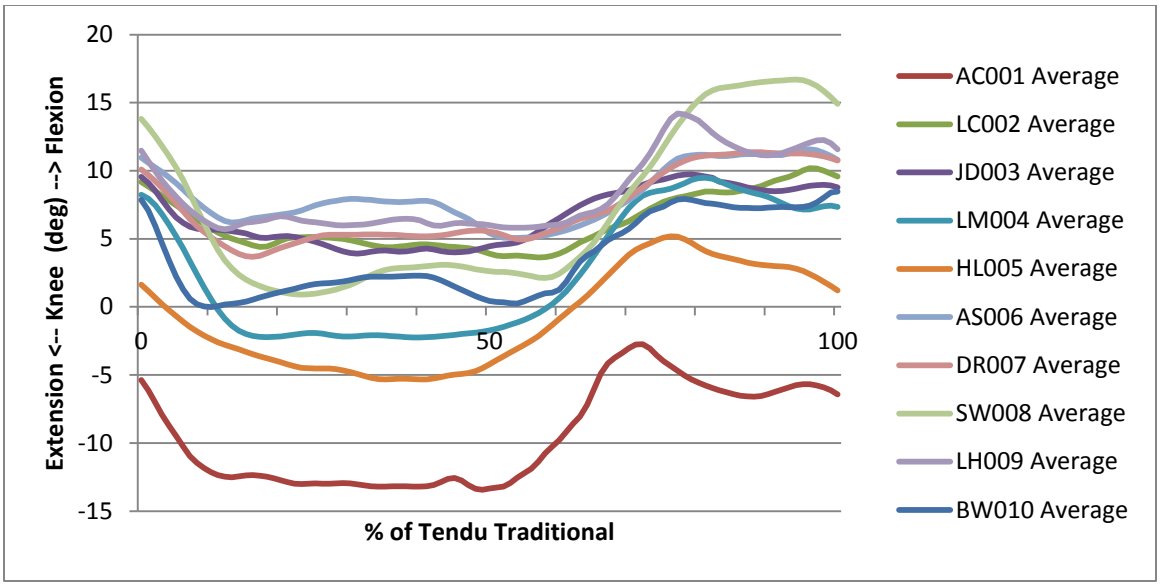

Figure 28: Third Position Average Right Knee Flexion with Traditional Closing

The Figure 28 shows the graph of flexion/extension for third position with traditional closing. Just like in first position subject AC001 is in full extension for tendu. The average range of motion of all the subjects is 10.3˚ and a standard deviation of 2.7˚. This is three degrees higher than first position for the right foot.

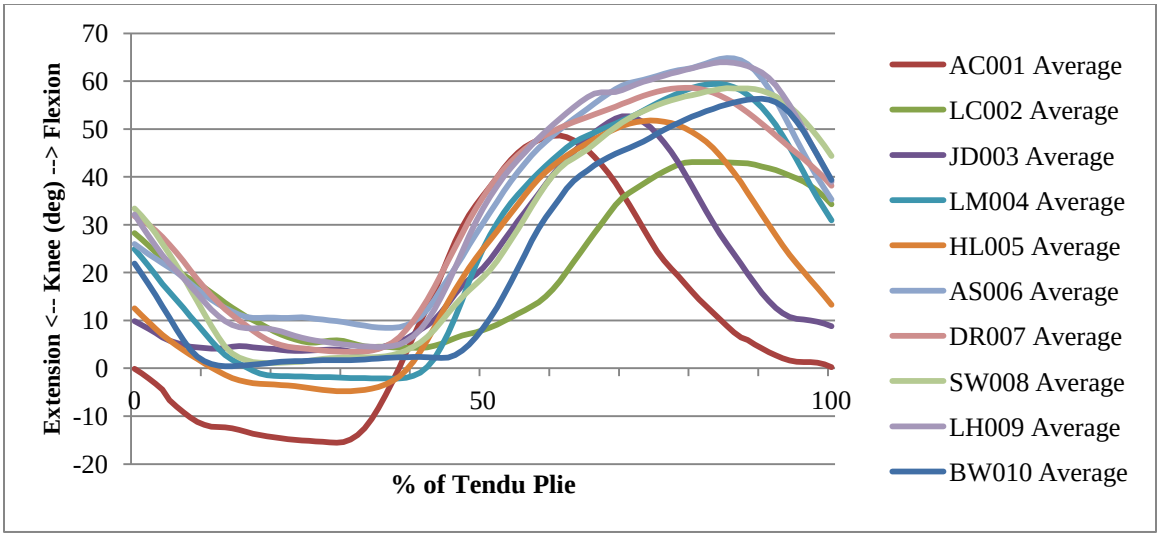

Figure 29: Third Position Average Right Knee Flexion with Plié Closing

The Figure 29 shows the graph of flexion/extension for the right knee with the plié closing. The average range of motion for all of the subjects is 56.9˚ and a standard deviation of 5.4˚. This is two degrees less than first position.

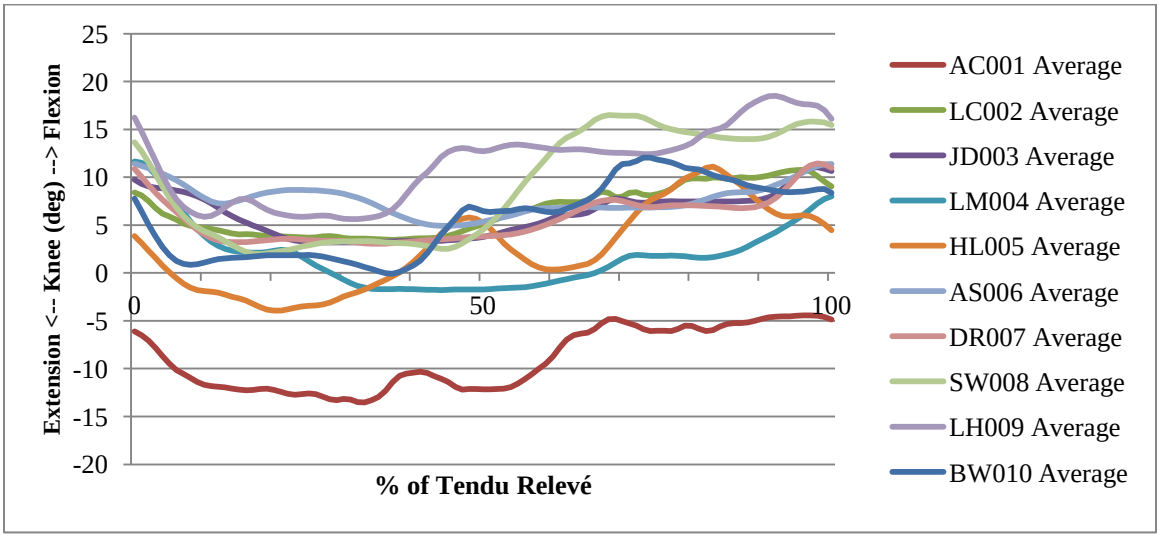

Figure 30: Third Position Average Right Knee Flexion with Relevé Closing

The Figure 30 shows the graph of flexion/extension for the right knee with the relevé closing. Still subject AC001 is in hyperextension for the tendu. The average range of motion for all of the subjects is 12.1˚ and a standard deviation of 3.4˚.

Table 10: Third Position Right Knee Abduction

Third Right			
Abduction/Adduction			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Significant
Plié	Significant	na	Significant
Relevé	Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

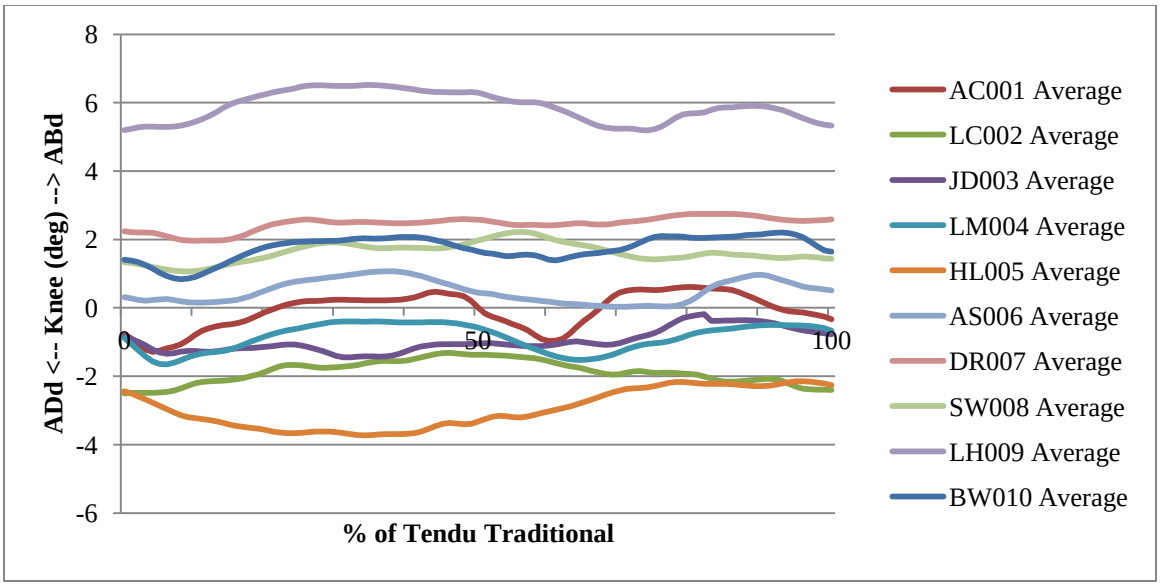

Figure 31: Third Position Average Right Knee Abduction with Traditional Closing

The Figure 31 shows the graph of adduction/abduction of the right knee with the traditional closing. The average range of motion of all of the subjects is 1.6˚ and a standard deviation of 0.4˚.

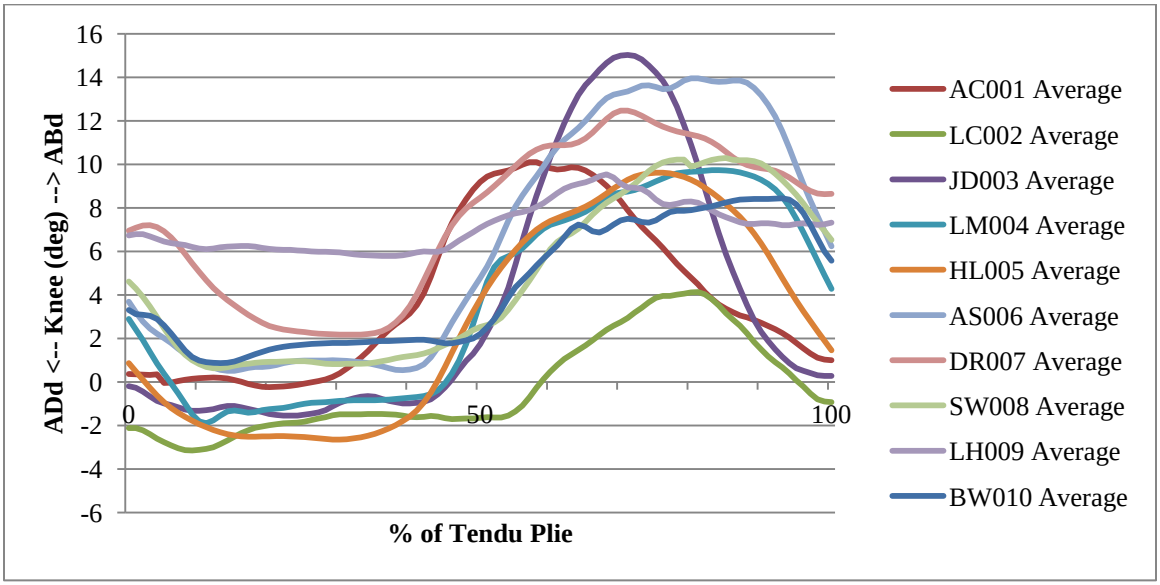

Figure 32: Third Position Average Right Knee Abduction with Plié Closing

The Figure 32 shows the graph of adduction/abduction of the right knee with plié closing. The average range of motion for all of the subjects' is.10.4˚ and a standard deviation of 4.0˚. This is over normal range of motion of 10˚.

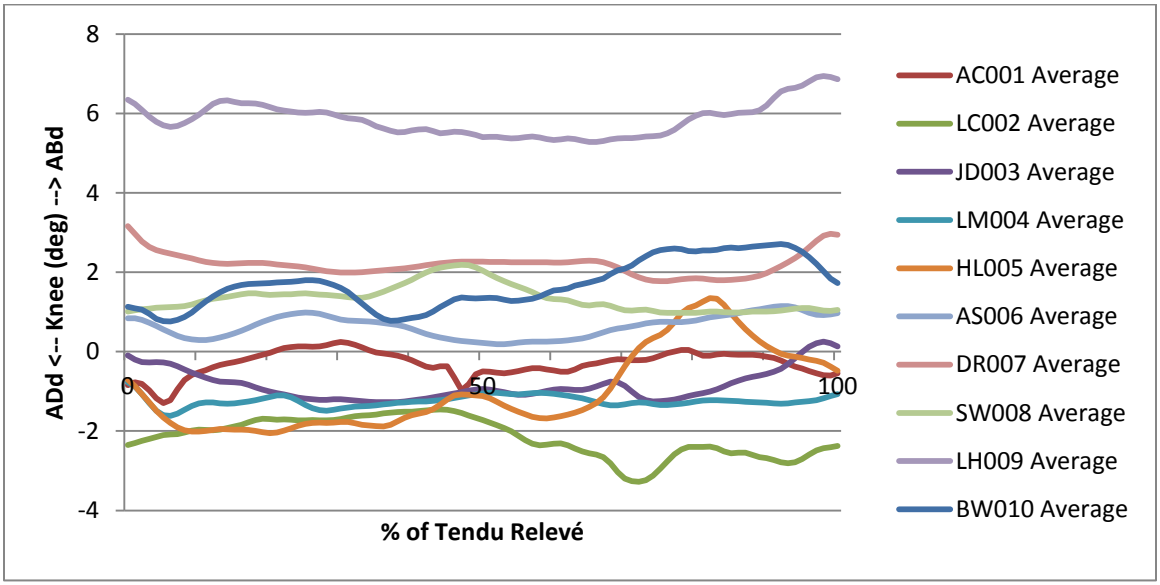

Figure 33: Third Position Average Right Knee Abduction with Relevé Closing

The Figure 33 shows the graph of the adduction/abduction for the right knee with the relevé closing. The average range of motion for all of the subjects is 2.1˚ and a standard deviation of 2.1˚.

Table 11: Third Position Right Knee Rotation

Third Right			
Rotation			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq 0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

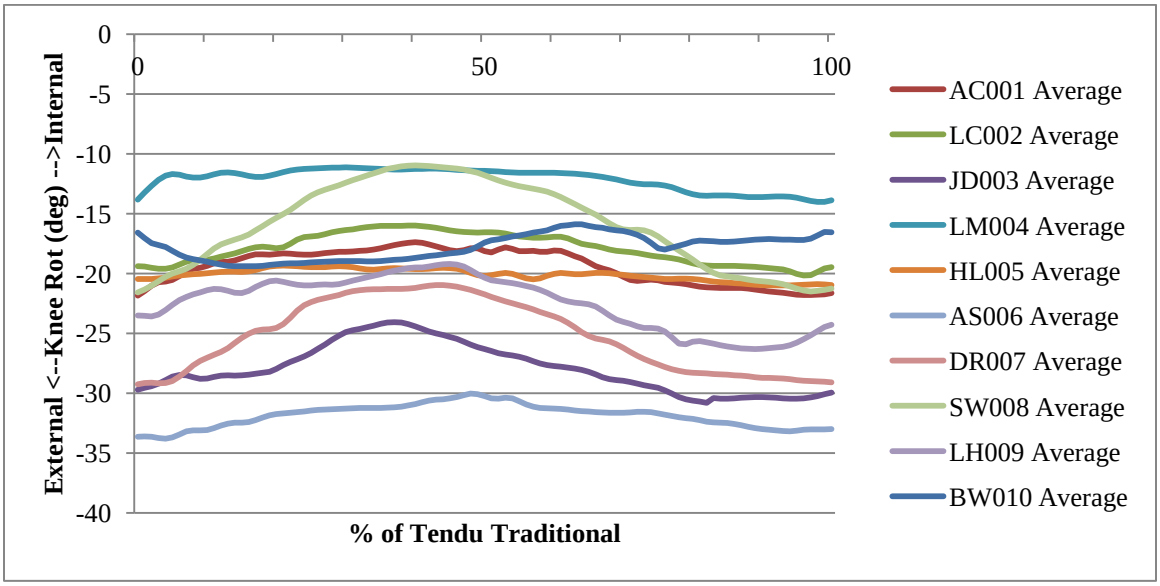

Figure 34: Third Position Average Right Knee Rotation with Traditional Closing

The Figure 34 shows the graph of the right knee rotation with traditional closing. The average range of motion for all of the subjects is 5.8˚ and a standard deviation of 2.8˚.

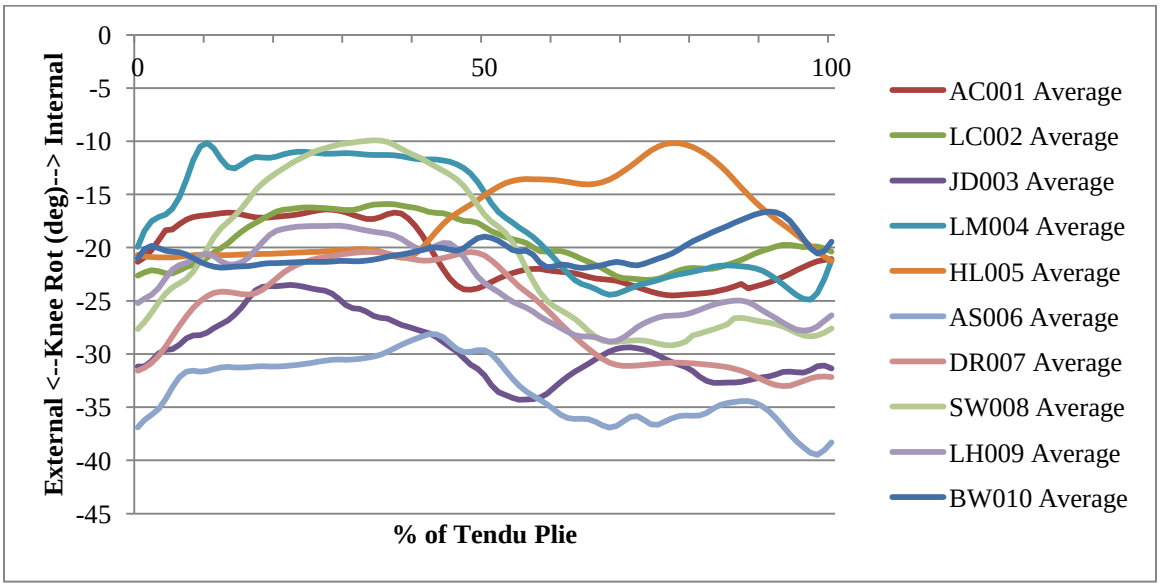

Figure 35: Third Position Average Right Knee Rotation with Plié Closing

The Figure 35 shows the graph of the right knee rotation with plié closing. The average range of motion for all of the subjects is 12.9˚ and a standard deviation of 3.8˚. This is slightly higher than what is the normal range of motion of 10˚.

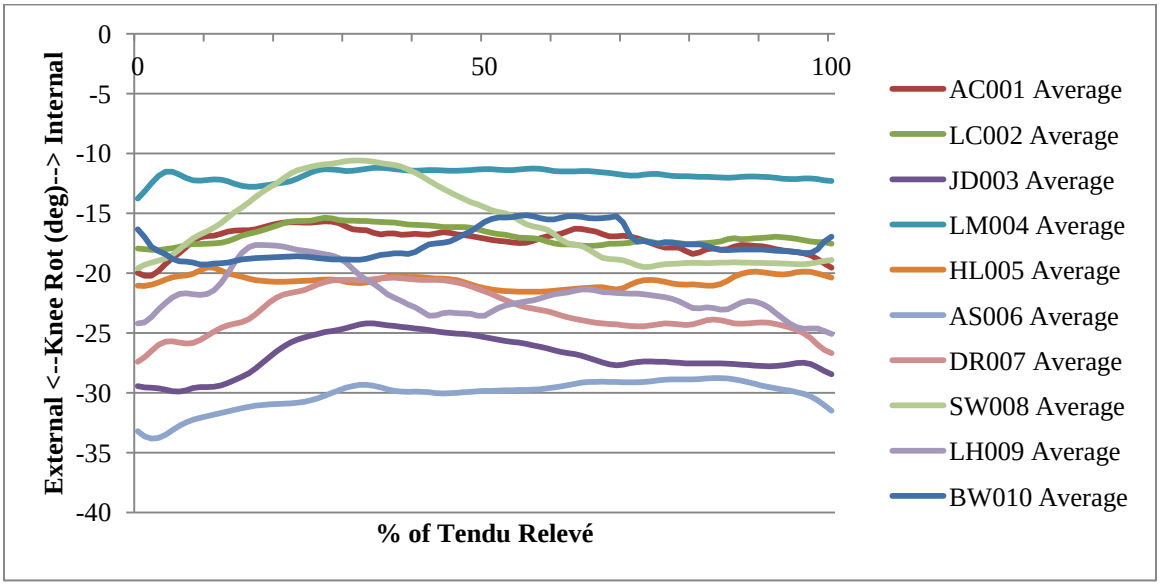

Figure 36: Third Position Average Right Knee Rotation with Relevé Closing

The Figure 36 shows the graph of the right knee rotation with the relevé closing. The average range of motion for all of the subjects is 5.7˚ and a standard deviation of 2.3˚.

3.2.2 Third Position Left Knee

The following graphs represent the angles of the left knee in third position. The graphs are grouped into flexion/extension, adduction/abduction, and rotation to show closings with the traditional, plié, and relevé closings.

Table 12: Third Position Left Knee Flexion

Third Left			
Flexion/Extension			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

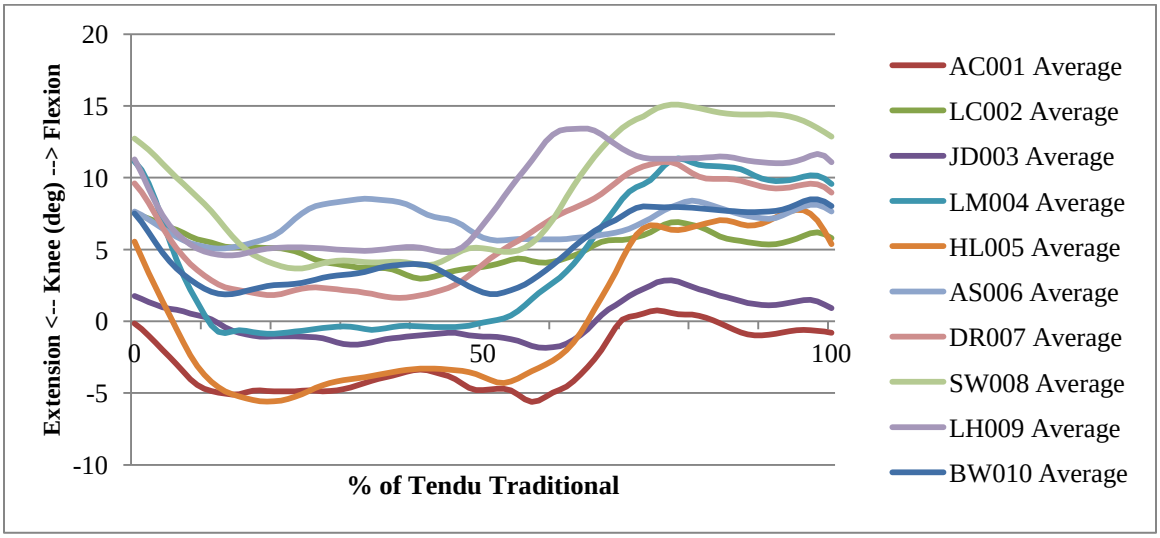

Figure 37: Third Position Average Left Knee Flexion with Traditional Closing

The Figure 37 shows the graph of flexion/extension of the left knee with the traditional closing. Subject AC001 is still in extension, but not as much as with the right leg. This was also seen in first position. The average range of motion for all of the subjects is 9.2˚ and a standard deviation of 3.02˚.

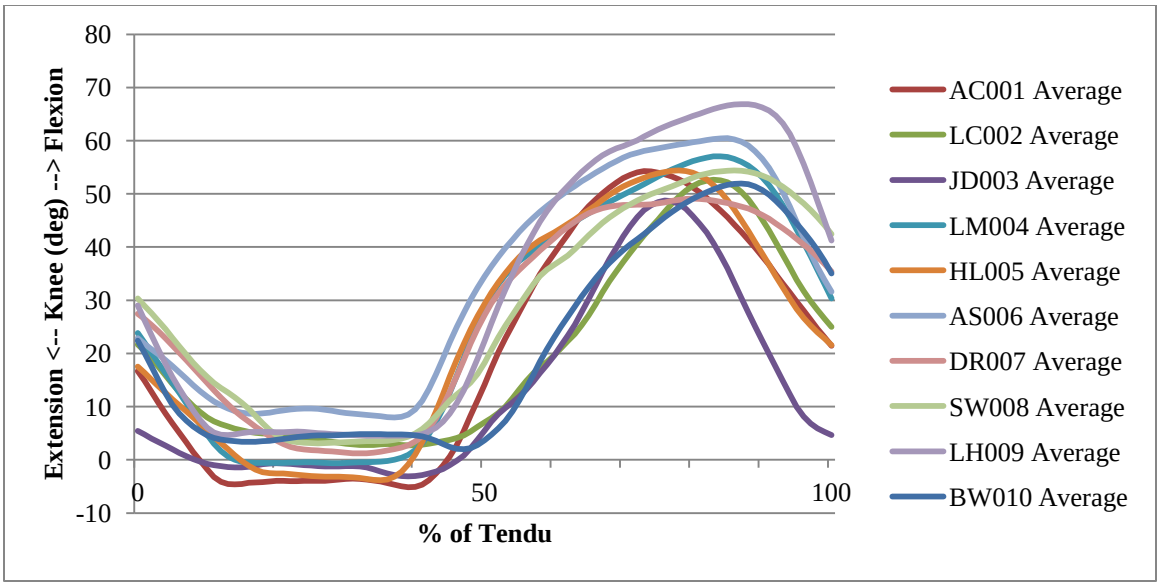

Figure 38: Third Position Average Left Knee Flexion with Plié Closing

The Figure 38 shows the graph of flexion/extension of the left knee with the plié closing. The average range of motion for all of the subjects is 54.9˚ and a standard deviation of 5.2˚. This is two degrees less than the right leg.

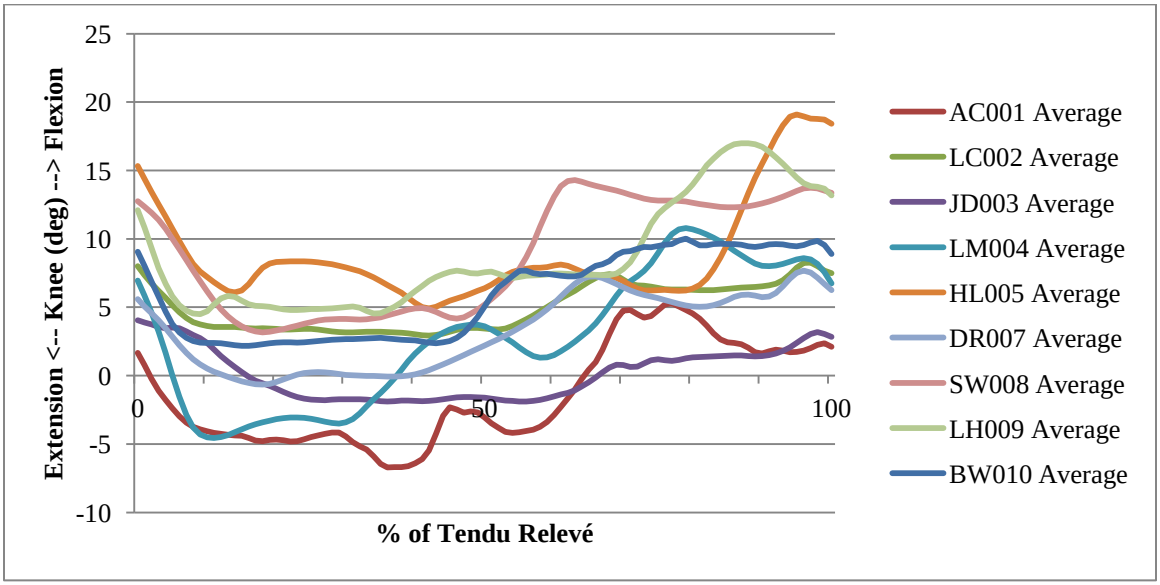

Figure 39: Third Position Average Left Knee Flexion with Relevé Closing

The Figure 39 shows the graph of knee flexion/extension for the left knee with the relevé closing. The average range of motion for all of the subjects is 11.6˚ and a standard deviation of 3.9˚.

Table 13: Third Position Left Knee Abduction

Third Left			
Abduction/Adduction			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

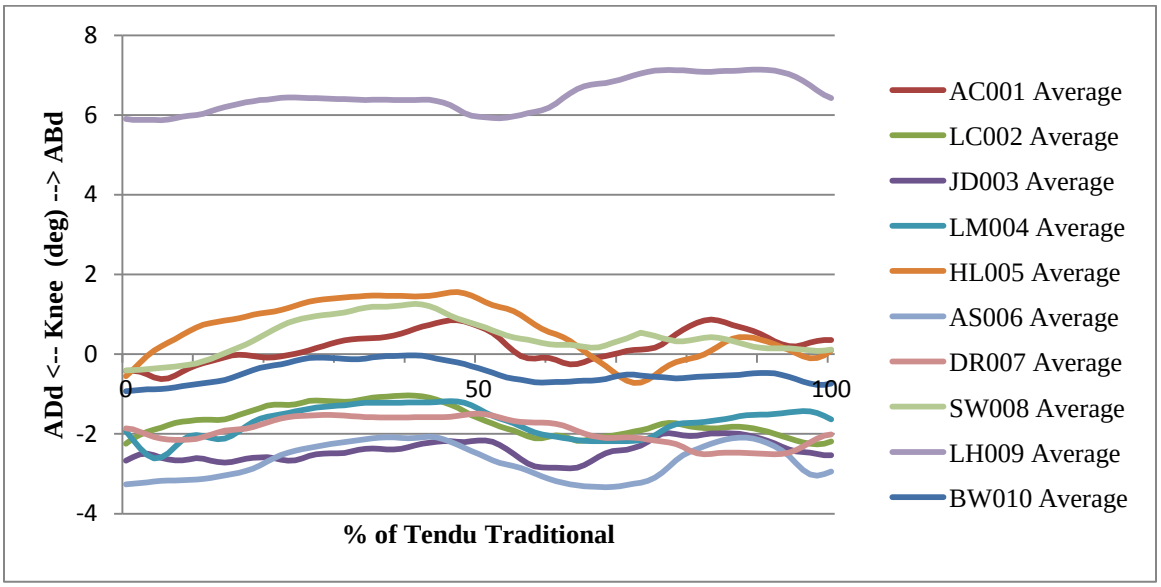

Figure 40: Third Position Average Left Knee Abduction with Traditional Closing

The Figure 40 shows the graph of the addiction/abduction of the left knee with the traditional closing. Just like in first position subject LH009 is in all adduction (Figure 22). The average range of motion for all of the subjects is 1.7˚ and a standard deviation of 0.4˚.

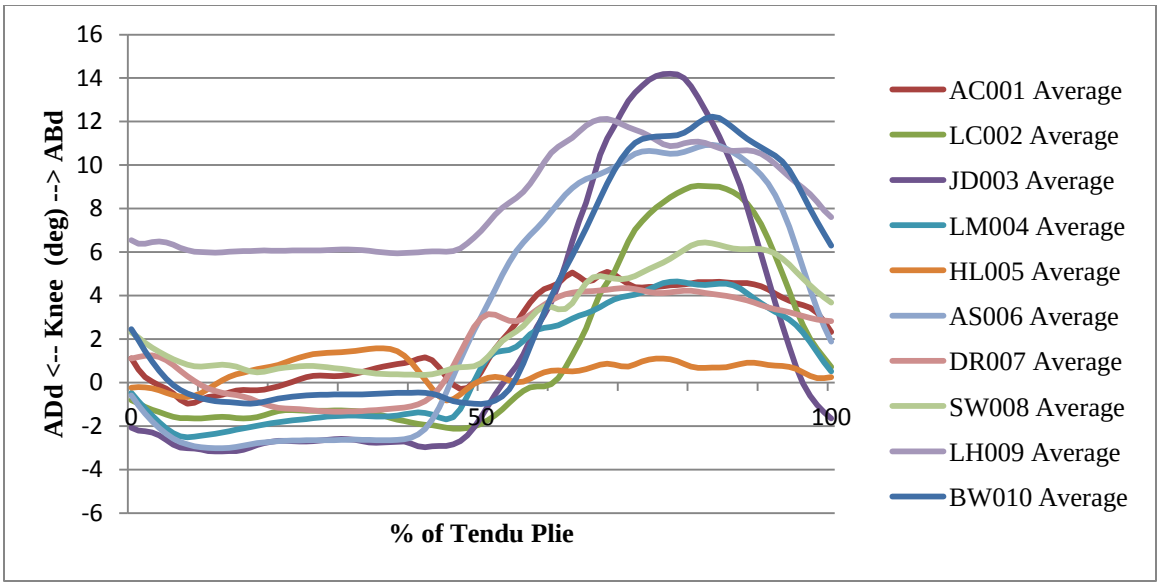

Figure 41: Third Position Average Left Knee Abduction with Plié Closing

The Figure 41 shows the graph of the adduction/abduction for the left knee with the plié closing. The average range of motion for all of the subjects is 8.9˚ and a standard deviation of 4.9˚.

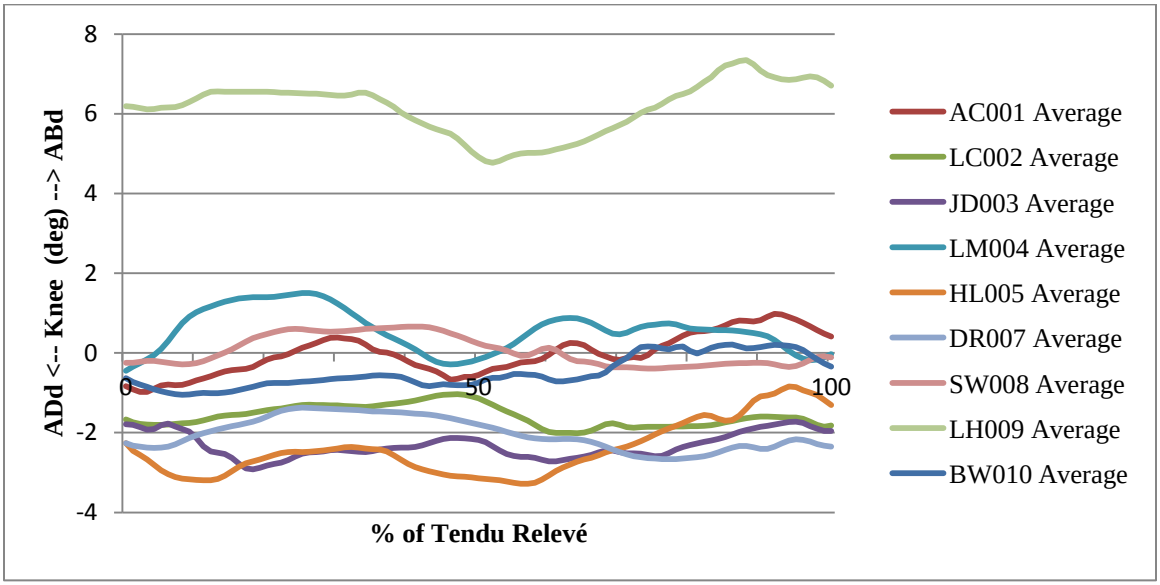

Figure 42: Third Position Average Left Knee Abduction with Relevé Closing

The Figure 42 shows the graph of the adduction/abduction for the left knee with the relevé closing. And just like in first position subject LH009 is more adducted than the rest of the subjects. The average range of motion for all of the subjects is 2.1˚ and a standard deviation of 0.6˚.

Table 14: Third Position Left Knee Rotation

Third Left			
Rotation			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

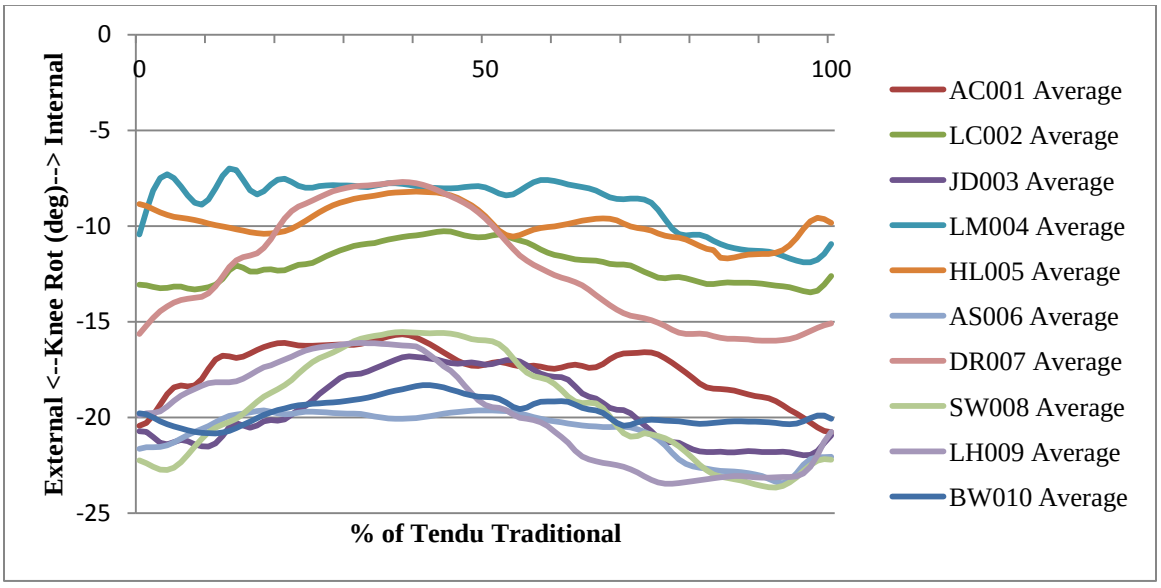

Figure 43: Third Position Average Left Knee Rotation with Traditional Closing

The Figure 43 shows the graph of the left knee rotation with the traditional closing. The average range of motion for all of the subjects is 5.8˚ and a standard deviation of 2.3˚.

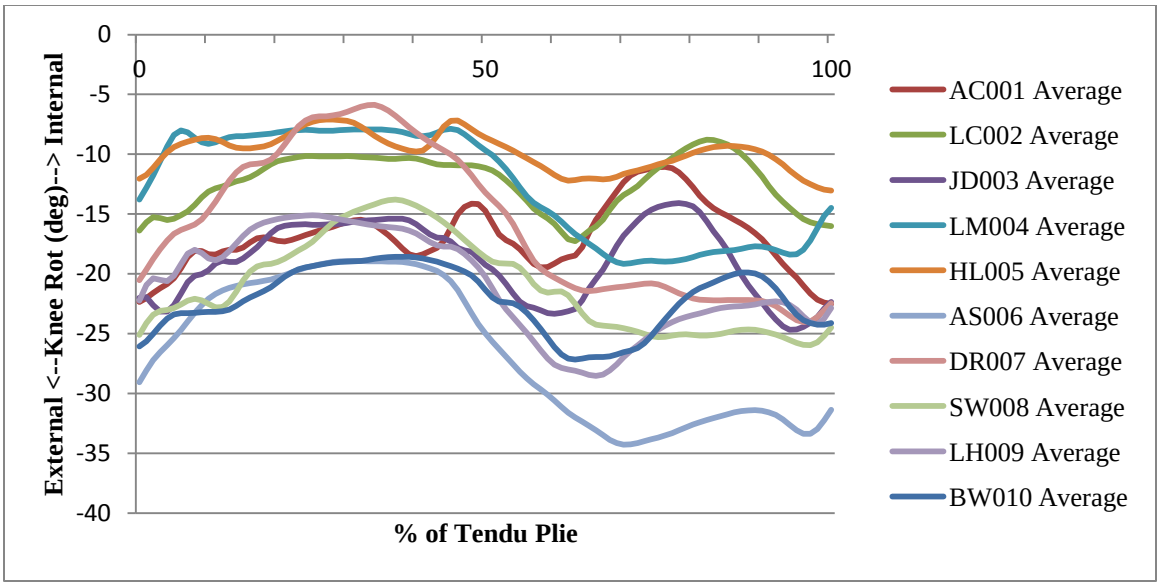

Figure 44: Third Position Average Left Knee Rotation with Plié Closing

The Figure 44 shows the graph of the left knee rotation with the plié closing. The average range of motion for all of the subjects is 12.6˚ and a standard deviation of 3.8˚.

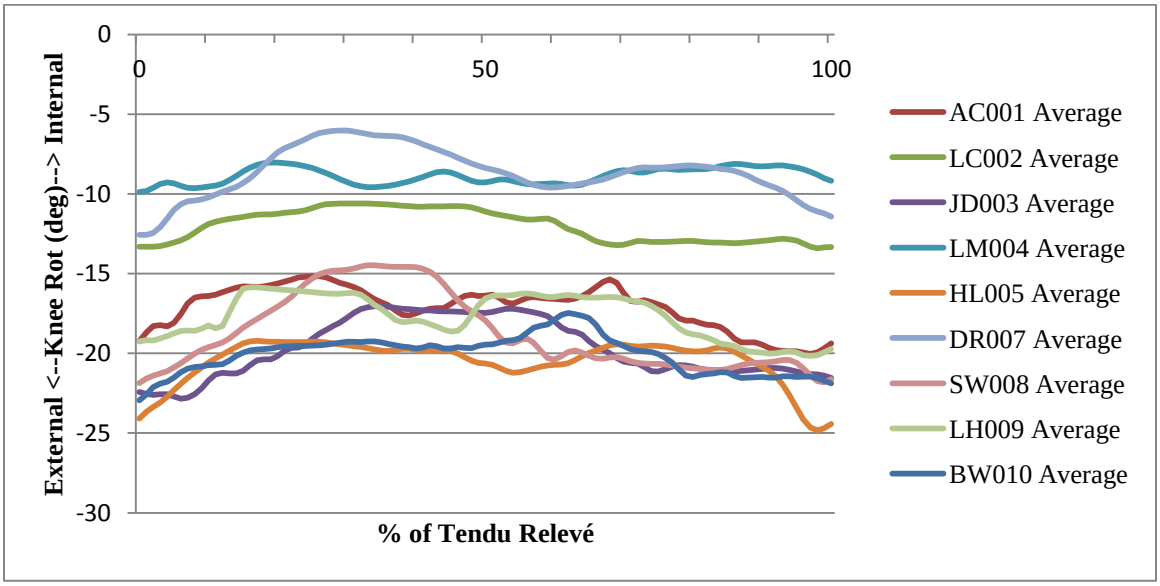

Figure 45: Third Position Average Left Knee Rotation with Relevé Closing

The Figure 45 shows the graph of the left knee rotation with the relevé closing. The average range of motion for all of the subjects is 5.7˚ and a standard deviation of 1.8˚.

3.3 Fifth Position

In fifth position the dancers their feet turned out at 180˚ just like in first and third position. This time their stand with their feet completely crossed so that the heel of one foot it touching the toe of the other foot. The subjects were asked to perform the trials with their most natural turnout and not to force the "ideal" turnout.

3.3.1 Fifth Position Right Knee

The following graphs represent the angles of the right knee in fifth position. The graphs are grouped into flexion/extension, adduction/abduction, and rotation to show closings with the traditional, plié, and relevé closings.

Table 15: Fifth Position Right Knee Flexion

Fifth Right			
Flexion/Extension			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

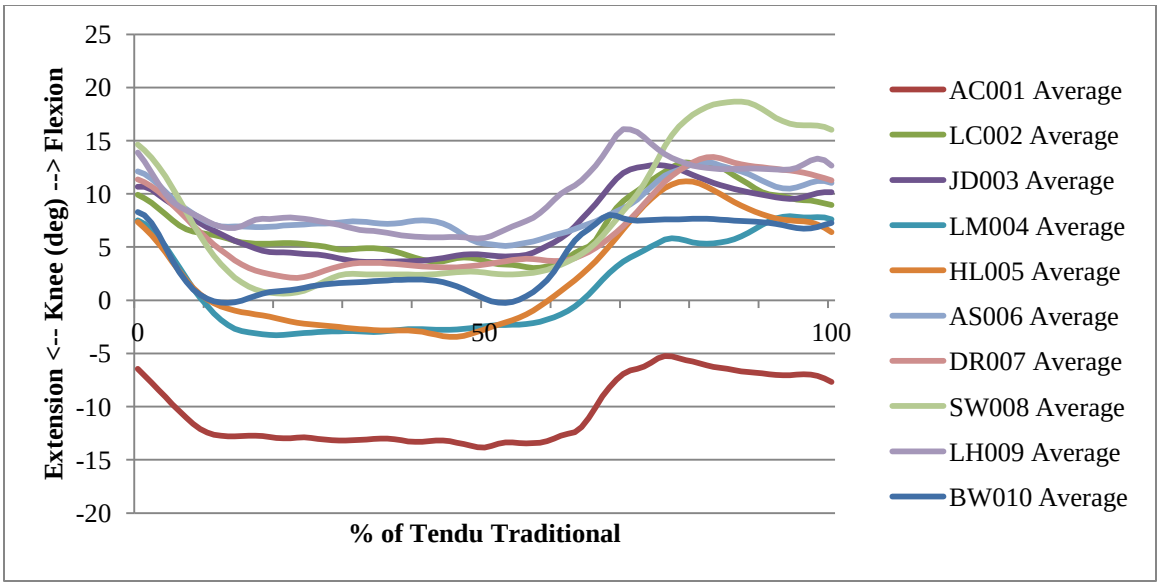

Figure 46: Fifth Position Average Right Knee Flexion with Traditional Closing

The Figure 46 shows the graph of the flexion/extension for the right knee with the traditional closing. Subject AC001 is still in hyperextension, just like in first and third position. The average range of motion for all of the subjects is 12.03˚ and a standard deviation of 3.06˚.

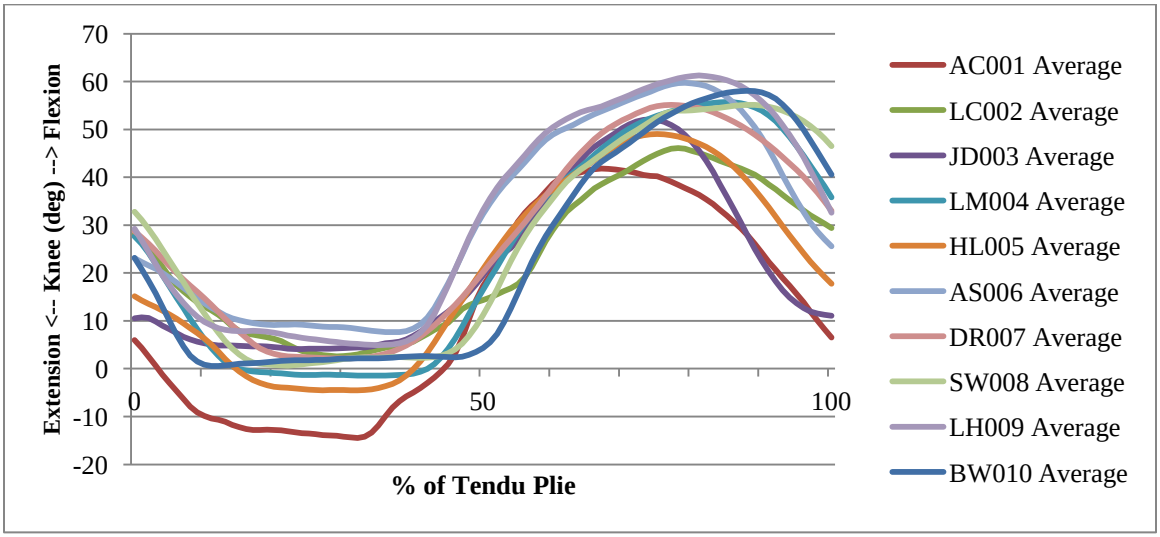

Figure 47: Fifth Position Average Right Knee Flexion with Plié Closing

The Figure 47 shows the graph of the flexion/extension of the right knee with the plié closing. The average range of motion for all of the subjects is 54.6˚ and a standard deviation of 4.3˚.

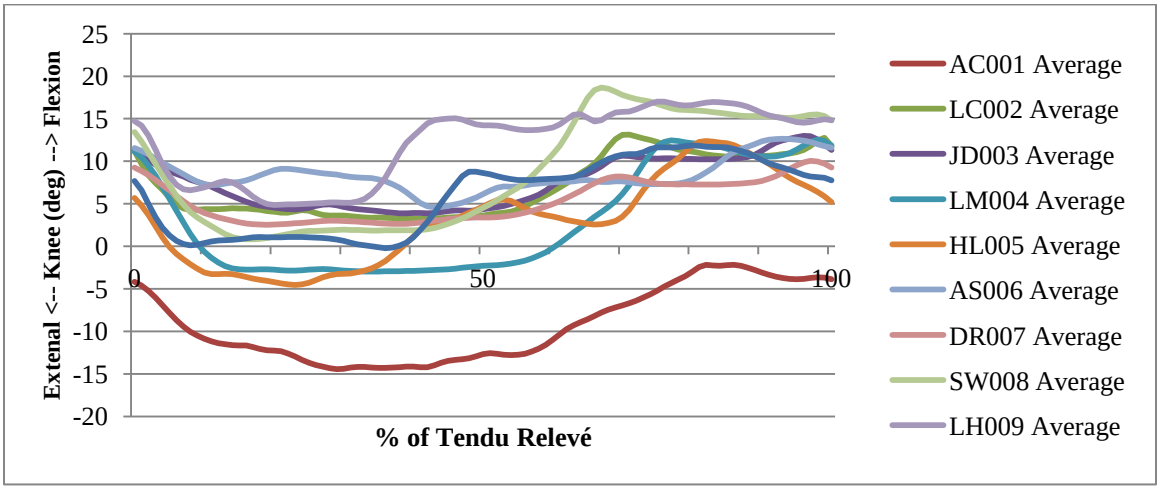

Figure 48: Fifth Position Average Right Knee Flexion with Relevé Closing

The Figure 48 shows the graph of the flexion/extension with the right knee in relevé closing. Subject AC001 is still in hyperextension just like in first and third position. The average range of motion for all of the subjects is 13.03˚ and a standard deviation of 3.6˚.

Table 16: Fifth Position Right Knee Abduction

Fifth Right			
Abduction/Adduction			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

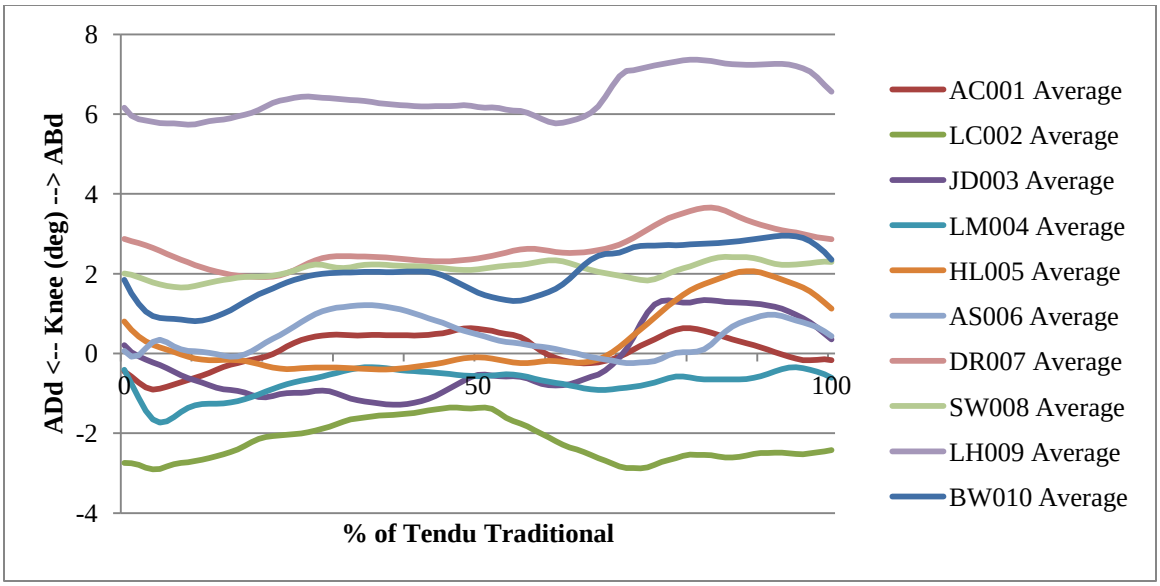

Figure 49: Fifth Position Average Right Knee Abduction with Traditional Closing

The Figure 49 shows the graph of the right knee in adduction/abduction for the traditional closing. LH009 is abduction much more than the other subjects. The average range of motion for all of the subjects is 1.9˚ and a standard deviation of 0.5˚.

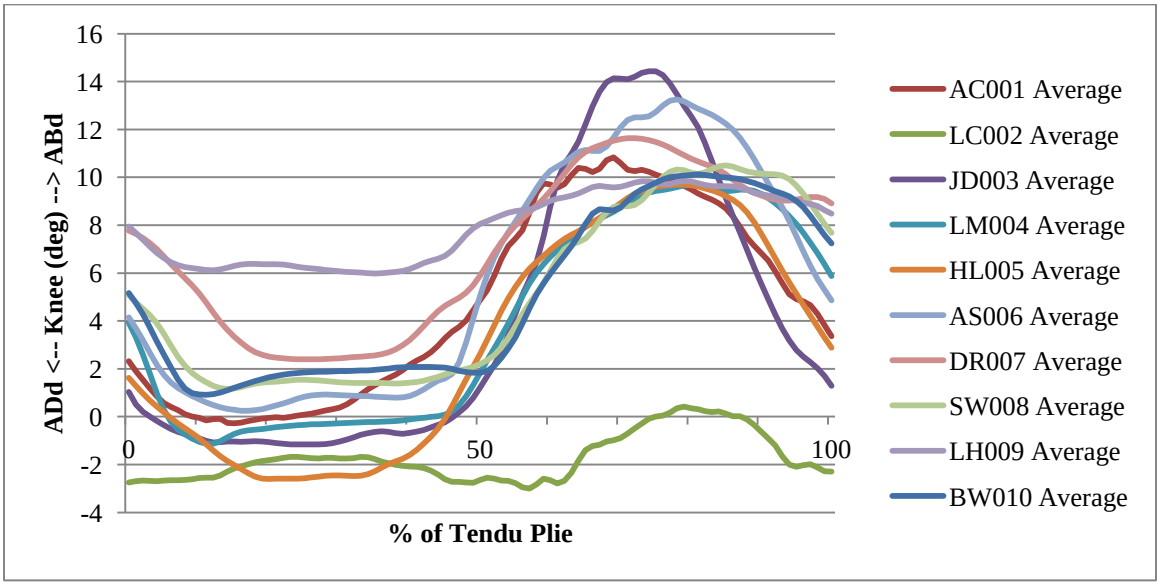

Figure 50: Fifth Position Average Right Knee Abduction with Plié Closing

The Figure 50 shows the graph with of the right knee adduction/abduction with the plié closing. The average range of motion for all of the subjects is 10.2˚ and a standard deviation of 3.6˚. This is double the normal range of motion for this axis.

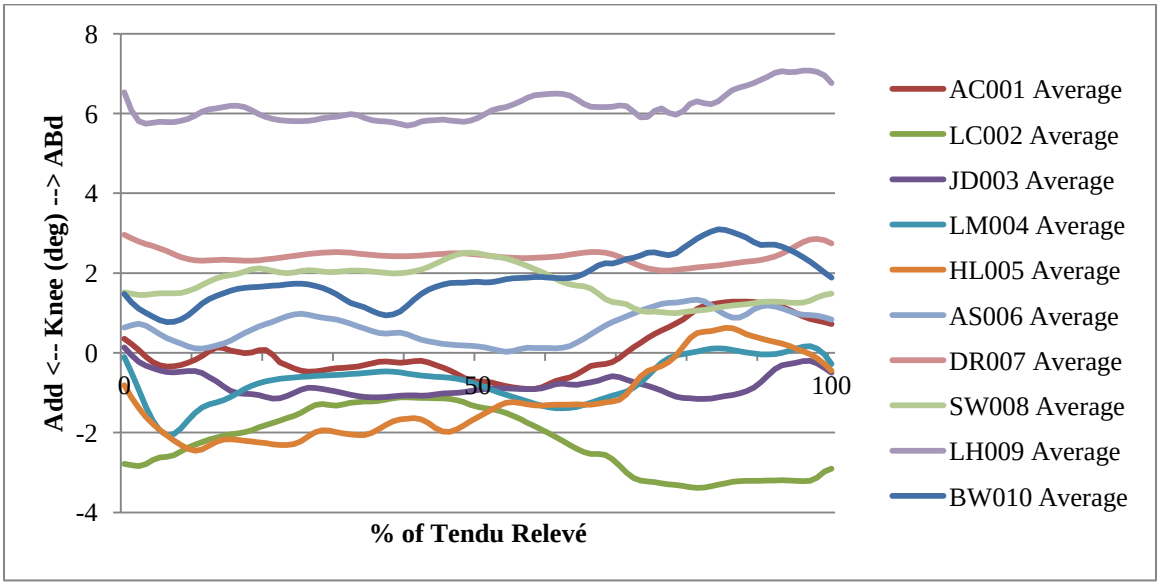

Figure 51: Fifth Position Average Right Knee Abduction with Relevé Closing

The Figure 51 shows the graph of the right knee adduction/abduction with the relevé closing. The average range of motion for all of the subjects is 2.2˚ and a standard deviation of 0.6˚.

Table 17: Fifth Position Right Knee Rotation

Fifth Right			
Rotation			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

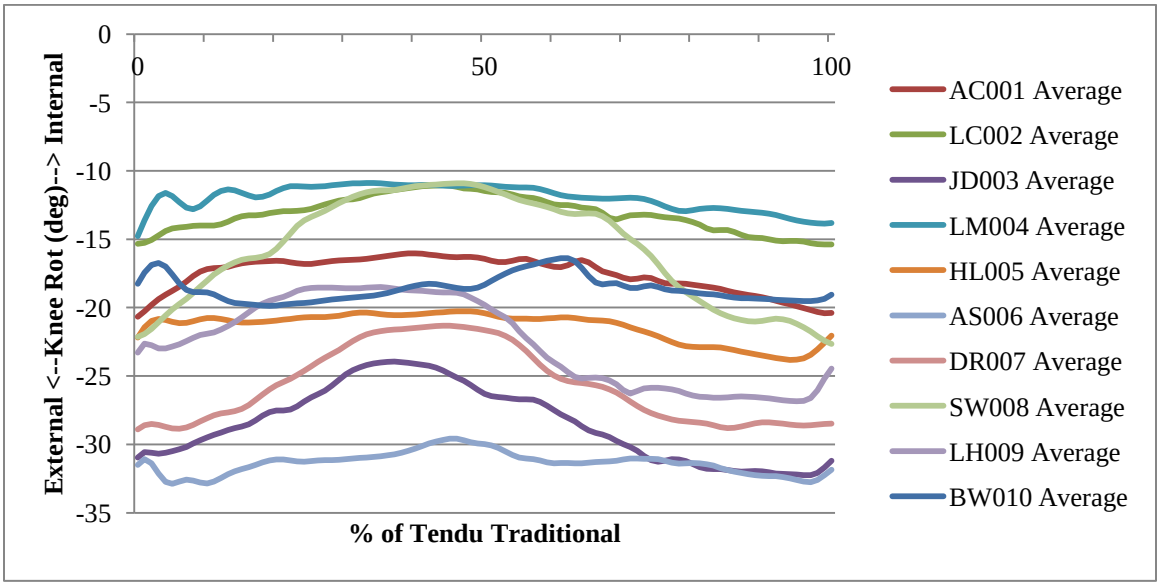

Figure 52: Fifth Position Average Right Knee Rotation with Traditional Closing

The Figure 52 shows the graph of the right knee rotation with the traditional closing. The average range of motion for all of the subjects is 6.5˚ and a standard deviation of 2.7˚.

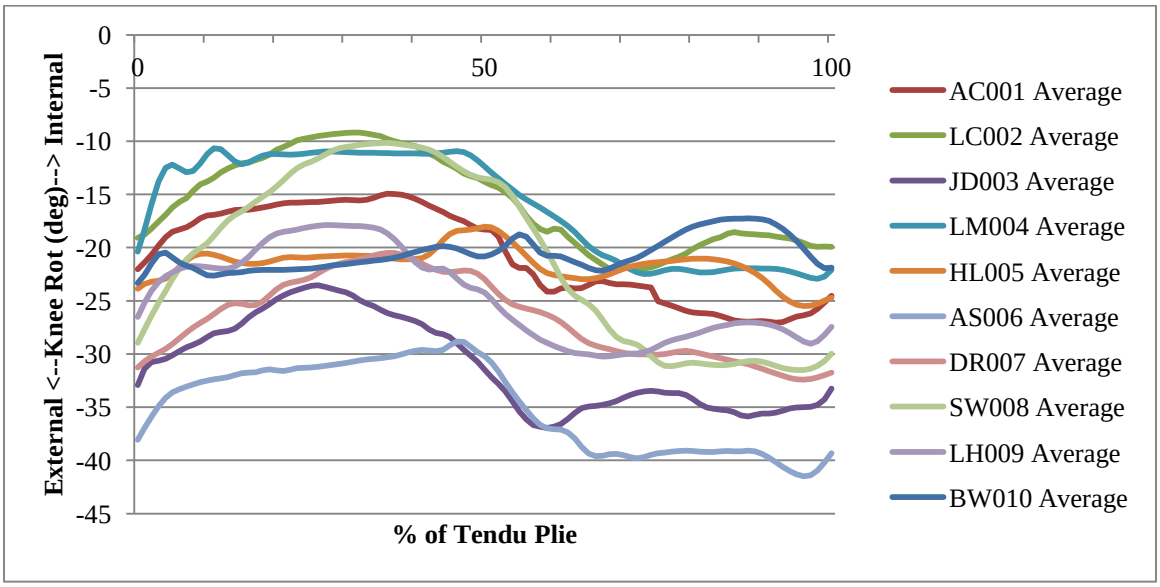

Figure 53: Fifth Position Average Right Knee Rotation with Plié Closing

The Figure 53 shows the graph of the right knee rotation with the plié closing. The average range of motion for all of the subjects is 13.3˚ and a standard deviation of 3.8˚.

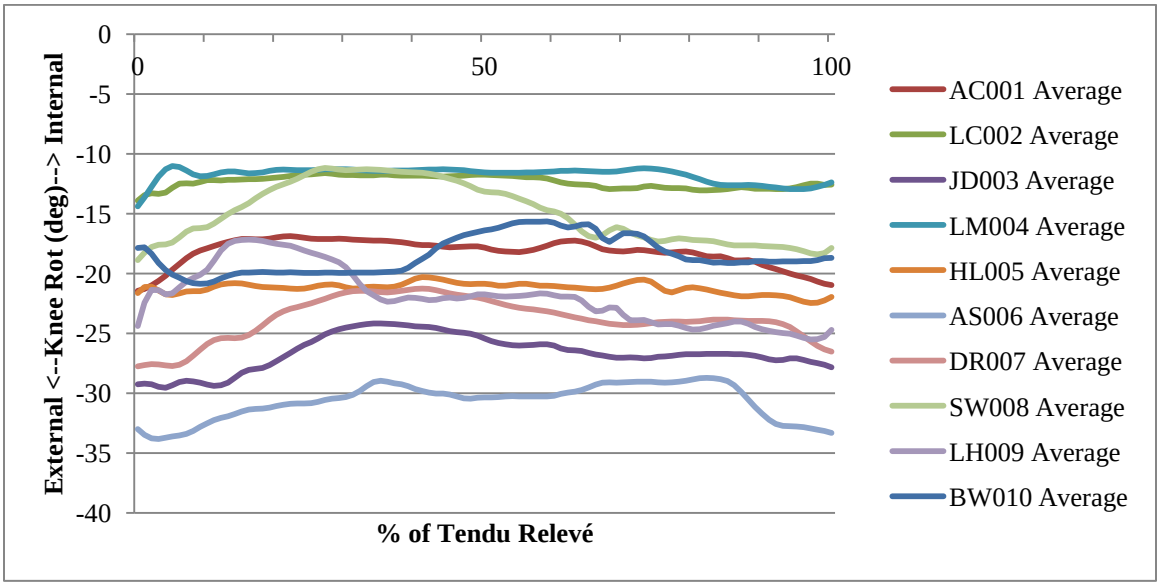

Figure 54: Fifth Position Average Right Knee Rotation with Relevé Closing

The Figure 54 shows the graph of the right knee rotation for the relevé closing. The average range of motion for all of the subjects is 5.9˚ and a standard deviation of 1.9˚.

3.3.2 Fifth Position Left Knee

The following graphs represent the angles of the left knee in fifth position. The graphs are grouped into flexion/extension, adduction/abduction, and rotation to show closings with the traditional, plié, and relevé closings.

Table 18: Fifth Position Left Knee Flexion

Fifth Left			
Flexion/Extension			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

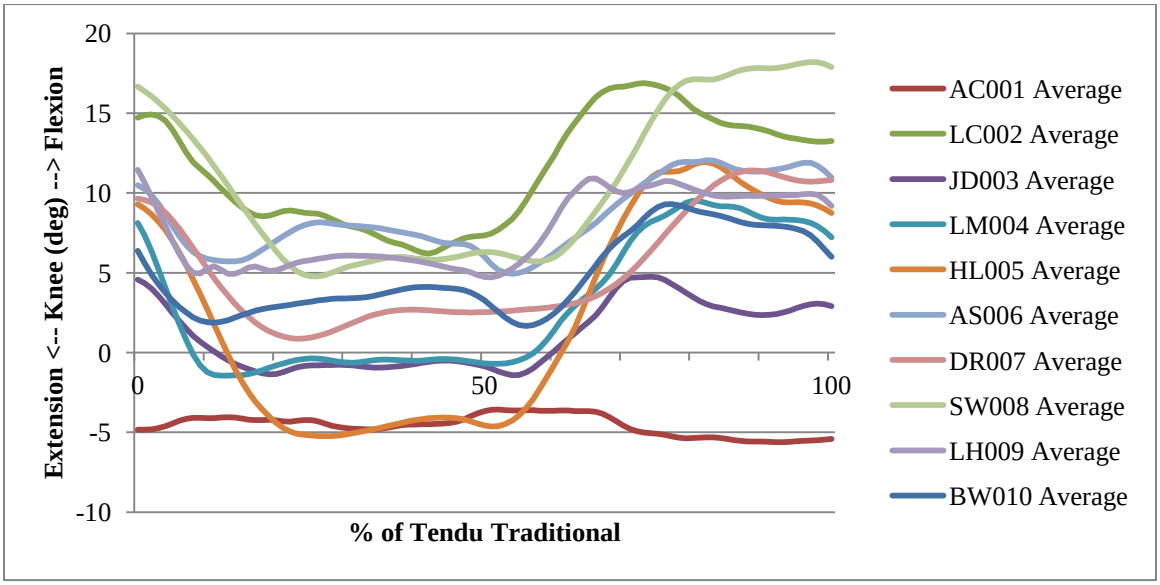

Figure 55: Fifth Position Average Left Knee Flexion with Traditional Closing

The Figure 55 shows the graph for the flexion/extension of the left knee with the traditional closing. The average range of motion for all of the subjects is 10.3˚ and a standard deviation of 4.1˚.

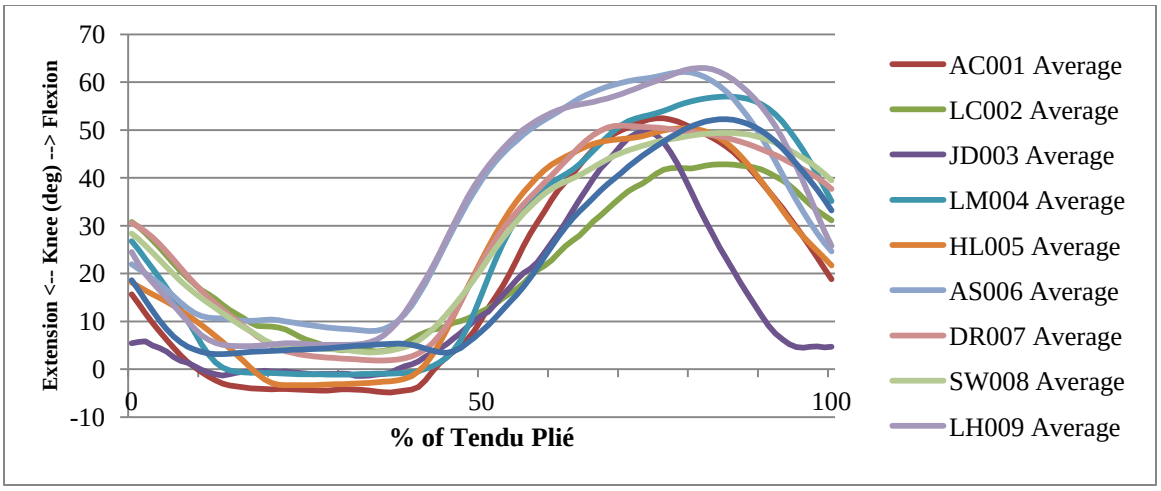

Figure 56: Fifth Position Average Left Knee Flexion with Plié Closing

The Figure 56 shows the graph of the flexion/extension of the left knee with the plié closing. The average range of motion for all of the subjects is 53.6˚ and a standard deviation of 5.3˚.

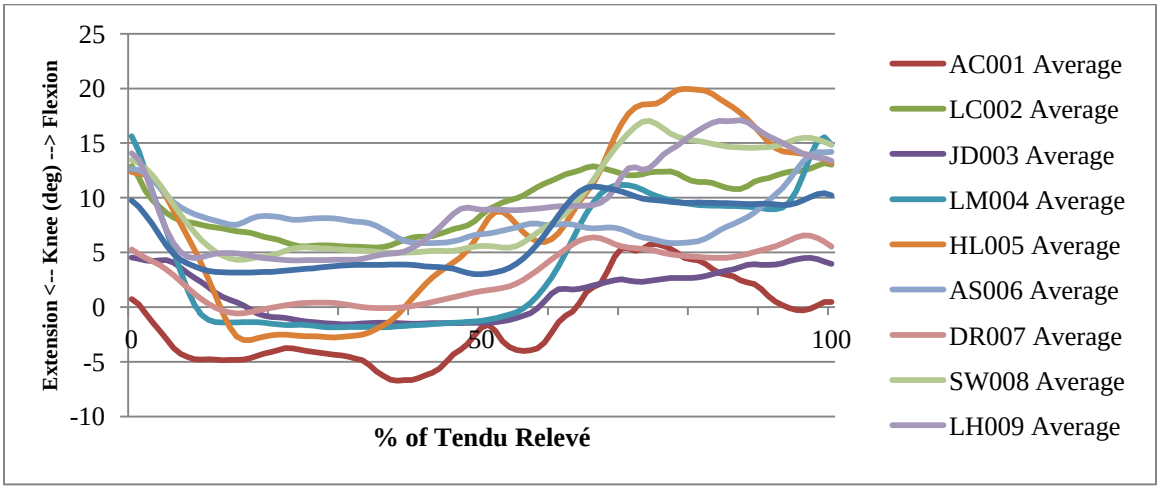

Figure 57: Fifth Position Average Left Knee Flexion with Relevé Closing

The Figure 57 shows the graph of the flexion/extension for the left knee with the relevé closing. The average range of motion for all of the subjects is 12.9˚ and a standard deviation of 5.4˚.

Table 19: Fifth Position Left Knee Abduction

Fifth Left			
Abduction/Adduction			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq 0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

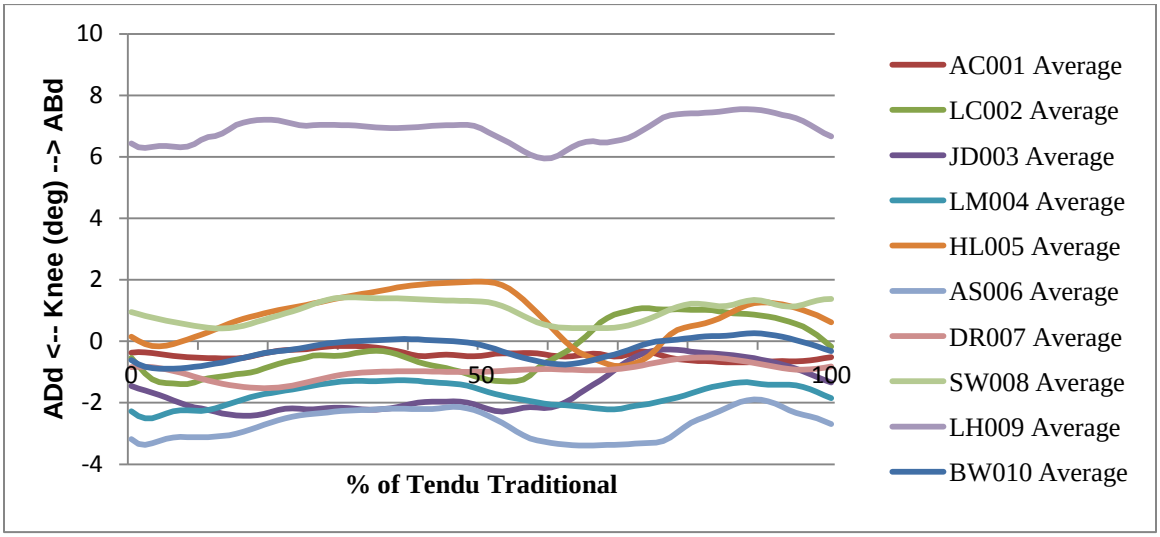

Figure 58: Fifth Position Average Left Knee Abduction with Traditional Closing

The Figure 58 shows the graph of the adduction/abduction of the left knee with the traditional closing. The average range of motion for all of the subjects is 1.8˚ and a standard deviation of 0.6˚.

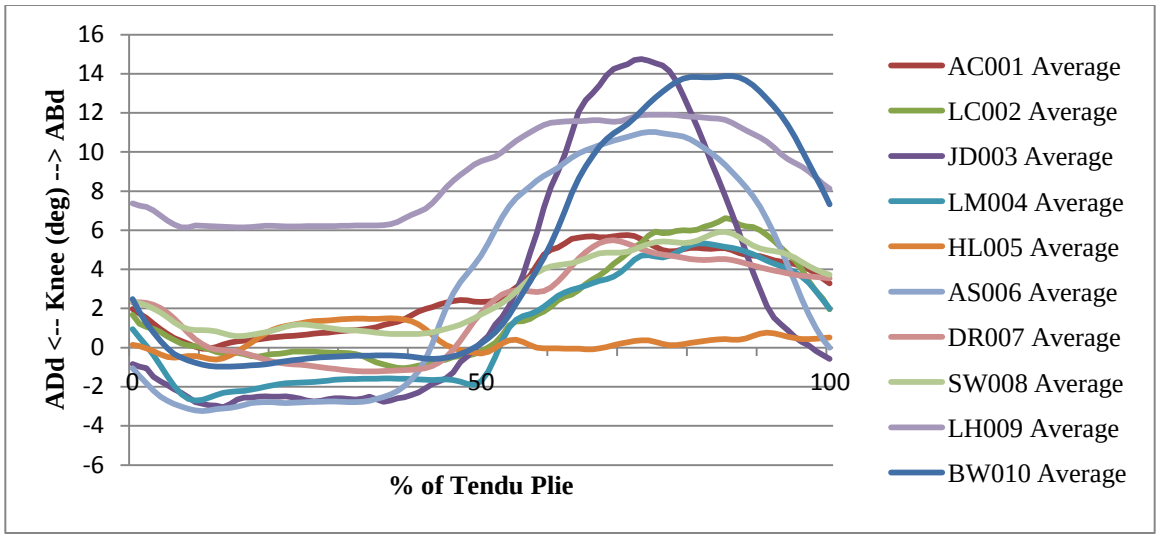

Figure 59: Fifth Position Average Left Knee Abduction with Plié Closing

The Figure 59 shows the graph of adduction/abduction of the left knee with the plié closing. The average range of motion for all of the subjects is 9.4˚ and a standard deviation of 4.8˚.

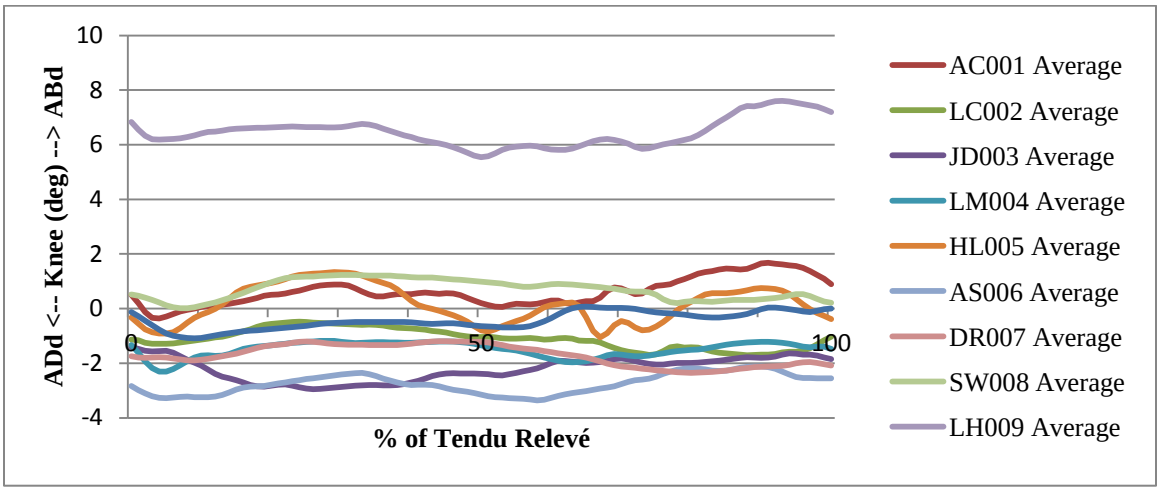

Figure 60: Fifth Position Average Left Knee Abduction with Relevé Closing

The Figure 60 shows the graph of the adduction/abduction of the left knee with the relevé closing. The average range of motion for all of the subjects is 1.8˚ and a standard deviation of 0.6˚.

Table 20: Fifth Position Left Knee Rotation

Fifth Left			
Rotation			
Pairwise	Traditional	Plié	Relevé
Traditional	na	Significant	Not Significant
Plié	Significant	na	Significant
Relevé	Not Significant	Significant	na

Significant $p<0.05$ and Not Significant $p\geq0.05$

The statistics were performed on the average range of motion of the ten subjects. The following are the averaged graphs that were used for this analysis.

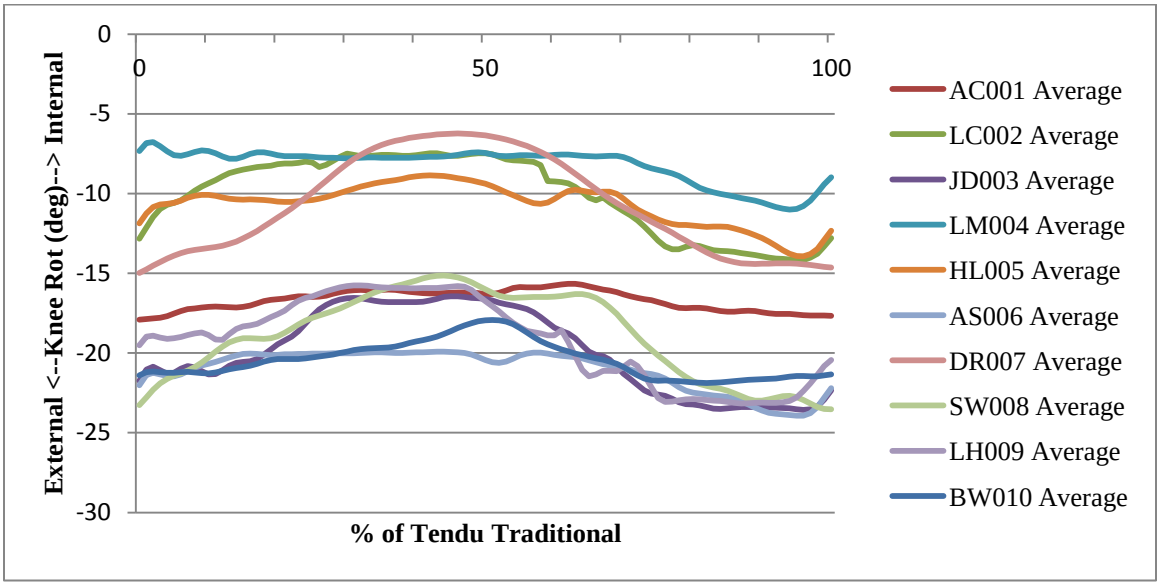

Figure 61: Fifth Position Average Left Knee Rotation with Traditional Closing

The Figure 61 shows the graph of the rotation of the left knee with the relevé closing. The average range of motion for all of the subjects is 6.3˚ and a standard deviation of 2.2˚.

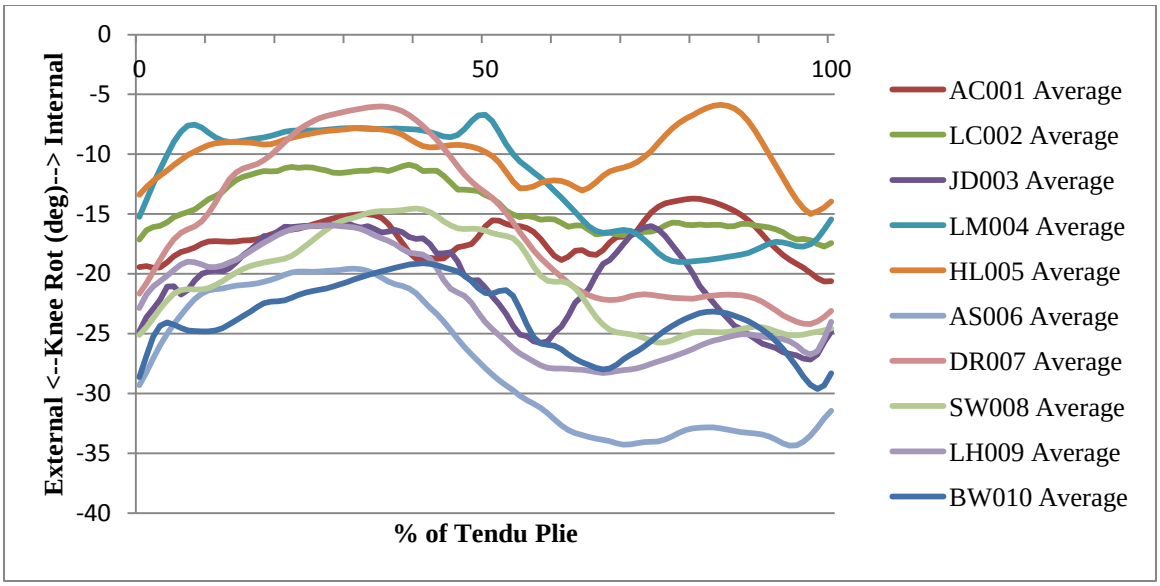

Figure 62: Fifth Position Average Left Knee Rotation with Plié Closing

The Figure 62 shows the graph of the rotation of the left knee with the plié closing. The average range of motion for all of the subjects is 13.2˚ and a standard deviation of 2.4˚.

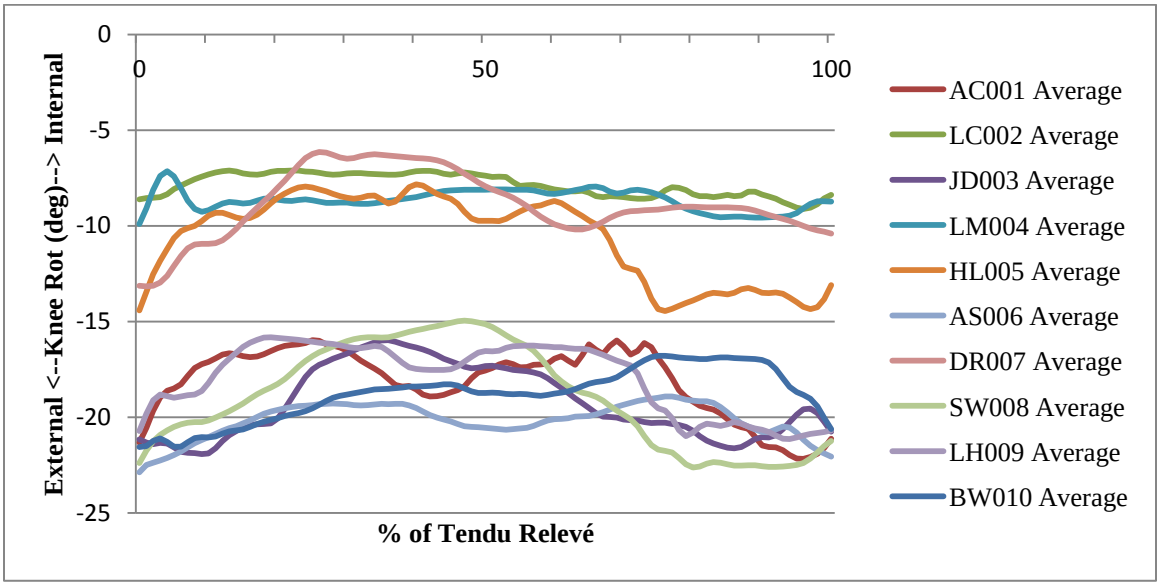

Figure 63: Fifth Position Average Left Knee Rotation with Relevé Closing

The Figure 63 shows the graph of the rotation of the left knee with the relevé closing. The average range of motion for all of the subjects is 6.5˚ and a standard deviation of 1.7˚.

CHAPTER 4:DISCUSSION

4.1 First Position

First position is when the feet are turned out at 180 degrees and the heels are touching. It is the first ballet position of a dancer to learn in the curare of their studies of dance.

4.1.1 Right Knee

In the first position the subject will have the most normal turnout as they cannot get extra rotation from their legs touching. In Figure 10 the subject performed the tendu with their right leg to the front. All of the subjects had their leg in extension with some flexion at the end of the movement as they pulled their leg back in to their body. One subject showed a large amount of extension compared to the rest of the subjects. After reviewing the model and the video from the VICON system it could be seen that AC001 was performing the tendu with the right leg in hyperextension. This was very apparent on the graph as subject AC001 data line was far from the rest of the subject and all but in the beginning in the negative rage of the graph; flexion is positive and extension is negative.

Data for subject AS006 was not included in to graph for the traditional closing because no data was collected. When performing the statistics on the data, the SPSS software was given a number that represents a missing number.

Next the plié closing in flexion/extension was reviewed Figure 11. All of the subjects followed the same curve in their movement and were close together. There were no subjects that

were out of the range of the rest of the subjects. With the average range of motion for the plié 58.2 degrees and the average for the traditional 6.9 degrees, this was probably were the significance came in. The large range of motion for the plié was expected, the movement requires the knees to bend in the direction of flexion.

Then the relevé closing with flexion/extension was reviewed (Figure 12). All of the subjects are very close together in there movement and the degrees in which they complete the move. Yet subject AC001 has the same shape of the movement, but was in full extension just like with the traditional closing. This was from her being in hyperextension when she extends her right leg. This more than likely comes from her performing extending movements from a young age with too much extension. The average range of motion for the relevé closing was 9.7 degrees this was a difference of 2.8 degrees with the relevé having more range of motion for the flexion/extension angles. It can be seen in the graph of the relevé closing (Figure 12) that there was a slight rise in the angle of the knee at the very end of the relevé closing. With the line of the graph representing flexion and extension the ascending line is viewed as flexion and a descending line seen as extension. This appears to be a slight flex of the knee as the subject closes the movement.

All of the subjects performed the movement in the normal range of flexion, zero to one hundred forty degrees[13]. They also performed in the normal range for extension, zero to five degrees, excepted for subject AC001[13]. Subject AC001 had extension of five degrees to a max of fourteen degrees for the traditional and relevé closings, this is in the negative direction on the graphs, and up to ten degrees of extension before starting the plié closing were she moved in to flexion.

The next set of data that was reviewed was in the axis of adduction and abduction, also called varus and valgus angles. For the first position right knee there was statistical significance, but there sphericity was not assumed and the Greenhouse-Geisser correction was used. With the main significance coming from the change from traditional to plié and relevé to plié, but not in the traditional to relevé closing as seen in the pairwise comparisons. Reviewing the data for the traditional closing (Figure 13). No data for subject AS006 was collected due to the subject not performing the correct movement and this was not fund until the data was being readied for analysis. The subjects had a small range of motion for this movement which was very understandable. The normal range of motion for this axis is five degrees. [13]The average range of motion for all of the subjects with the traditional closing was 2.3 degrees. All but subject HL005 start with a little abduction at the beginning of the tendu and on the way back to the closing they were in adduction. Only subject HL005 did the opposite, adduction and then abduction. The other interesting result of this graph was that subject LH009 has a higher starting point on the graph. She starts at just above four degrees and moves up to six degrees of abduction and then back to four degrees with adduction with a total range of motion of two degrees which was right in line with all of the other subjects. All of the other subjects start between 1.5 and -4.5 degrees and ending in that same range.

Next set of data that was reviewed was the plié closing in addiction and abduction (Figure 14) for all ten subjects. The plié data was very interesting in that eight of the subjects have about the same movement and two of the subject the very different movements from each other and the rest of the group. Most of the subjects have very little movement for the first half of the tendu, but as they start to close to the plié at the end of tendu they start to abduct. Two of these (subjects HL005 and DR007) start with adduction and then move into abduction at the

tendu. Subject JD003 had a very large difference in comparison to the rest of the subjects. She had all most no movement in this axis until plié closing where she had a range of motion of 16 degrees. This means she abduct at the beginning ($^1/_2$ to ¾ of the graph) of the closer and then adducted at the end (last ¼ of the graph) of the closing. It was very smooth like a bell curve unlike all of the other subjects that did this movement. They did not do it with as much range of motion and as smooth. The last interesting subject's data on this graph was subject LC002; she had almost no movement with a range of motion of 3.1 degrees where the average range of motion for all of the subjects was 8.9 degrees. The average range of motion for all of the subjects was almost 4degrees higher than what was consider the normal range of motion for the knee in this axis, five degrees. All but two of the subjects have range of motion outside of what was considered to be normal for adduction/abduction. This was a cause for some concern, yet was understandable because with the knee bending there is more way the knee can move. When the knee is straight it can reach times when it cannot move in certain direction like a robot in gimbel lock. But with knee bend there are more degrees of freedom for the knee which could explain why the subjects had a greater range of motion of the plié closing in the adduction/abduction axis.

Finally the relevé closing was reviewed with all ten subjects (Figure 15). Just like with the traditional closing the range of motion was very small only 2.3 degrees average for all of the subjects. And again all but one of the subjects was in the same small range of angles, between 2 to -4 degrees. Subject LH009 was out of the range of the other subjects, just like in the traditional closing and has the range. This could be coming from ligament laxity from an over stretching of the ligament over time. This could eventually lead to joint laxity, but from the data it cannot be determined how far it has gone. The subjects still started out with abduction and moved to

adduction as they closing to the relevé closing. So they would abduct as they extend their leg and then adduct as they brought their leg back into the body and closed to the relevé. And subject HL005 still had the opposite movement with adducting and then abducting just like she did in the traditional tendu closing.

The last of the data to be reviewed for the first position right leg is the rotational axis. There was statistical significance for this set of data. The sphericity was not assumed so the Greenhouse – Geisser correction was used. The main significance was in the traditional to plié and relevé to plié. There was no significance in the traditional to relevé.

The first graph (Figure 16) was the results of the knee rotation for the right with a traditional closing. All of the subjects are in the same range of movement with the group having an average range of motion of 5.3 degrees. The concerning thing from looking at the data was that range of the subjects' rotation if from negative 10 to negative 29 degrees, but could just be from where they started their movement. All of the subjects start except for two start with internal rotation, which is the graph going in the positive direction, and go into external rotation to end the movement. Some subjects have very little range of motion like AC001 (4.3 degrees), LC002 (3.2 degrees), and LM004 (3.6 degrees). Other had a larger range of motion DR007 (7.8 degrees), SW008 (9.3 degrees), LH009 (6.2 degrees), and JD003 (5.3 degrees). Subject HL005 had almost no rotational movement with an average range of motion of 1.8 degrees. Subject BW010 had the opposite rotation from the rest of the subjects by going in external rotation and then closing with internal rotation.

The next graph (Figure 17) was the closing for the right knee with the plié closing. The plié closings rotations were not as smooth the rotation for the traditional closings. The starting

rotations are still in the negative range of 15 to 35 degrees. But the average range of motions for all of the subjects is 12.4 degrees, which was more than double the average range of motions for the traditional closing. Most of the subjects are starting with internal rotation and moving to external rotation half way through the tendu and then going back to internal rotation, but to a smaller degree. Two of the subjects (HL005 and BW010) started with very little rotation and then have internal rotation as they start the plié and end the plié in external rotation. Subject AS006 starts with internal rotation and stay steady with very little rotation though all of the tendu and closing with only external rotation at the very end of the plié to close.

The last graph (Figure 18) for the rotation for the right knee was with closing to the relevé. The relevé closing were smoother than the plié closing, but still not as smooth as the traditional rotations. The average range of motion for all of the subjects was half of that for the plié closing at 6.1 degrees. The subjects that had the relatively flat rotation for the traditional closing also had it for the relevé closing. Still subjects SW008, DR007, JD003, and LH009 started with internal rotation and then with external rotation, with very little rotation are the end of the tendu when they were closing to the relevé. Still subject BW010 was the opposite by starting with external rotation and them moving to internal rotation. All of the subjects had relatively little rotation for the last half of the tendu when they were closing to the relevé.

From reviewing the statistics there was statistical significance between the traditional and plié closing and plié and relevé closing for all of the angles of the knee. This maybe because there was greater difference in the knee angles because the knee was bending in the plié were as the traditional and relevé closings are straight leg closings. There was only statistical significance between the traditional and the relevé closing for the knee angle of flexion/extension and this

maybe because the subjects had a higher range of motion for the relevé closing than the traditional closing.

4.1.2 Left Knee

The first section of data to be reviewed for the first position left leg was the flexion/extension axis. There was statistical significance for this set of data. The sphericity was not assumed so the Greenhouse – Geisser correction was used. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between traditional and relevé, and between plié and relevé.

For the graph (Figure 19) for the left knee in flexion and extension with the traditional closer shows the subject more together than the flexion/extension for the right knee. As expected the subjects started out in extension and ended with flexion as they pulled their leg back to their body. Subjects AC001 and HL005 had the most extension. AC001 still was mainly in extension, but not to the hyperextension that she was doing with the right leg, only going to about 4.5 degrees of extension. All of the subjects had an average range of motion of 6.1 degrees. Subject AS006 had a very interesting movement in that she started in extension and went to flexion and then back to extension.

The graph (Figure 20) of the flexion/extension plié closing was what you would expect for the plié. All of the subjects start with a small amount of the extension as they extended their leg for the tendu and then flex their knee in the last half of the graph for the plié closing. The overall average range of motion for all of the subjects was 58.8 degrees and this was well within the normal range for knee flexion. Subject AC001 was in still hyperextending, just like she did

with the right leg, but to the same extent. Only about negative five degrees instead of the negative ten degrees for the right leg.

The last graph for the flexion/extension was the graph (Figure 21) for the relevé closing. This was a smaller range than in the plié closing because the knee was not bending, but very similar to the traditional closing with have a straight leg to closing. All of the subjects start with a small about of extension as they extend their leg and then bring the leg back to the body with flexion. Some subjects start the flexion at about the half-way point of the tendu, when they start bring their leg back to the body, but then re-extension as they feel that they have more room to complete the closing because of the position of the body in the relevé closing. Subject AC001 was still had more extension than the rest of the subjects, but still not the too extent that she has on the right leg.

The next section of data to be reviewed for the first position left leg the abduction/adduction axis. There was statistical significance for this set of data. The sphericity was not assumed so the Greenhouse – Geisser correction was used. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between plié and relevé, and not statistical significance between plié and relevé.

The first of the graphs for abduction/adduction was the graph (Figure 22) for the traditional closing. All of the subjects are in the same range of the graph, between 0.5 to 3 degrees for the start and finish of the movement. Only subject LH009 was out of this range, starting and ending in around 5 degrees. All of the subjects had an average range of motion of 2.2 degrees, which was well in the normal range for abduction and adduction of the knee. Even subject LH009 was in this range at 1.8 degrees for range of motion even thou she was not with

the rest of the subjects for the range of angles. All of the subjects started off with a sight abduction and at just past 50 percent of the tendu they started to adduction and stayed almost flat in their movement to the end of the closing.

Next the graph (Figure 23) for the plié closing was looked in the abduction/ adduction axis. All of the subjects start out with very little movement, but a slight abduction movement. At 50persent of the tendu, when the plié was beginning, there was a large abduction movement followed by an equal adduction movement to end the plié, 75 to 100 present of the tendu. All of the subjects had a different range of motion for the plié closing, some had almost no movement like HL005 (3.5 degrees) and one had a large amount of movement JD003 (18.3 degrees). Most were closing to the overall average of 9.3 degrees of range of motion. Subject LH009 still was out of the starting and ending angles from the rest of the subject at 5 degrees, where the rest started and ending in the zero to negative 3 degrees range.

The finale graph (Figure 24) to look at for abduction/adduction for the left knee was the graph with the relevé closing. The movement of all of the subjects was very similar to the traditional closing. The subjects start with abduction and at 50perscent of the tendu close with adduction of the knee. All of the subject except for one start and end in the negative 0.5 to 3 degrees and only subject LH009 starts and ends at 5 degree of. The average range of motion for all of the subjects was 2.1 degrees. Subject AS006 was a little different in that she was relatively flat and at 50 percent of the tendu she starts to abduct and holds that position until the end of the tendu.

The last set of graphs to look at for the left knee in first position was the rotational data. There was statistical significance for this set of data. The sphericity was assumed. The pairwise

comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between plié and relevé, and not statistical significance between plié and relevé.

First the graph (Figure 25) for the left knee rotation with the traditional closing was reviewed. Some of the subject has a relativity flat movement in the rotation while others have more prevalent movement from internal to external rotation. The overall average range of motion for all of the subjects was 4.9 degrees. Subjects LC002 (3.3 degrees), LM004 (4.4 degrees), HL005 (3.2 degrees), AS006 (3.2 degrees), and BW010 (3.8 degrees) have very little movement. Other subjects have a large amount of movement like DR007 (8.5 degrees). All of the subjects had a movement of starting with internal rotation and ending with external rotation. Only subject BW010 started with external rotation and moved to internal rotation gradually though the tendu. Some like subjects DR007 and SW008 did the first half of the tendu in internal rotation and the second half in external rotation.

The next graph (Figure 26) to be reviewed was for knee rotation with plié closing. All of the subjects had more movement in the plié closing than in the traditional closing with an average range of motion of 11.6 degrees. A lot of the subjects had a not so smooth movement of the entire graph, but had and overall of trend of starting with internal rotation, going into external rotation at 50 percent and then back to internal then ending the tendu in external rotation. This was most prevalent in subjects AC001 and JD003 with having equal internal then external rotation in the first half of the graph, but from 50 to about 75 percent internal and then back to external rotation for the last quarter of the data.

The last graph (Figure 27) to be reviewed was the knee rotation for the relevé closing. The relevé rotation looks similar to that of the traditional closing. The average range of motion

for all of the subjects was slightly higher at 5.5 degrees. Still most of the subjects have almost no movement. Subjects DR007 and SW008 do not follower this trend, they start with large amount of internal rotation and at about 25 percent they move to external rotation (SW008 does it sharply) until they get to 50 percent of the tendu and then level off like the rest of the subjects. All of the subjects have the trend of internal at the beginning of the tendu and external at the end, just not to the extent as these two subjects.

From reviewing the statistics there was statistical significance between the traditional and plié closing and plié and relevé closing for all of the angles of the knee. This maybe because there was greater difference in the knee angles because the knee was bending in the plié were as the traditional and relevé closings are straight leg closings. There was only statistical significance between the traditional and the relevé closing for the knee angle of flexion/extension and this maybe because the subjects had a higher range of motion for the relevé closing than the traditional closing.

4.2 Third Position

Third position is the first ballet position where the feet cross in front of each other. The dancer only crosses the foot half way by bringing heel of the front foot the arch of the back foot. This position starts engage the abductors of the hip.

4.2.1 Right Knee

The first section of data to be reviewed for the third position right leg was the flexion/extension axis. There was statistical significance for this set of data. The sphericity was assumed. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between traditional and relevé, and between plié and relevé.

The first graph (Figure 28) that was reviewed was the right knee flexion/extension with the traditional closing. All of the subjects have the same movement through the tendu. They start in extension as the move the moving foot away from the body, at the 50 percent mark of the tendu as they start to bring the moving foot back to the body they start to flex the knee and the movement levels off for the last quarter of the graph. The average range of motion for all of the subjects is 10.3 degrees with the highest average range of motion for one of the subjects was 16.3 degrees. The average range of motion for all of the subject was three degree higher in third position than in first position. All of the averages are will with in the normal range of motion for the human body. Only subject AC001 was not in the range of the other subjects, just like in the first position flexion/extension she was in hyperextension of the knee. She also has a greater range of motion in third position than in first position, 11.6 and 9.9 degrees respectively. Two of the subjects (AS006 & BW010) flexed in the middle of the first 50 percent of the tendu when rest of the subjects are just extending.

The next graph (Figure 29) to be reviewed was the graph with the flexion/extension closing to plié. The graph follows the expected path for flexion/extension with a bent knee. Still subject AC001 has hyperextension at the beginning of the tendu when she was extending her leg. The average range of motion for all of the subjects was 56.9 degrees for the plié closing. This was to be expected because the subjects are bending their knee for the plié closing and was well within the normal range for flexion/extension of the knee. Subject AC001 had the highest range of motion and LC002 had the lowest, 65.5 and 46.7 degrees respectively.

The graph (Figure 30) for the flexion/extension axis if the closing to relevé. The relevé closing in flexion/extension does not look as expected like the traditional and plié. The subjects do start in extension and move to flexion at the 50 percent mark, but it was jagged and not

smooth like the other closing. Some of the subjects to follow the same movement of the others. HL005 start in extension and moves into flexion at 25 percent through 50 percent at the same level as her starting point and then moves back to extension, not to degree as the first time, and back to flexion at 70 percent, but goes higher than when she flexed her knee the first time, and back to extension at 85 percent. BW010 starts in extension and moves to flexion at 50 percent and then even more flexion at 75 percent and then holds steady to the end of the tendu. But some subjects move just like they did in the traditional closing by going into extension and then to flexion at 50 percent and hold steady to the end of the tendu. And just as expected subject AC001 was still in hyperextension.

The next section of data to be reviewed for the third position right leg was the abduction/adduction axis. The sphericity was not assumed so the Greenhouse – Geisser correction was used. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between traditional and relevé, and between plié and relevé.

The first graph (Figure 31) to be reviewed for abduction/adduction for the right knee was the traditional closing. There was very little movement in this axis which was to be expected, so the average range of motion for all of the subject of 1.6 degrees was to be expected. This was almost no movement of the knee. The highest range of motion for one of the subject was 2.4 degrees (LC002). All but one of the subjects abduct for the first half of the tendu and adduct for the last half, just like in the first position. Only subject HL005 goes in the opposite direction (adduct then abduct). One subject (AC001) did do something slightly different in that at 50 percent she adduct the same range she abducted and then quickly re-abducted (at 70 percent) to the same level as before and then gradually adducted to the end of the tendu. But for most all of the subjects their movement was very flat with only slight can from abduction to adduction.

The next graph (Figure 32) to be reviewed was the abduction/adduction with plié closing. This graph shows more movement of the knee in the abduction/adduction axis than the traditional closing. The subjects start with adduction at the beginning, hold flat until 50 percent of the tendu and then start the plié to close and then start into abduction, which was the largest range of motion, and then back to adduction to the starting level of the tendu to the end of the tendu. The average range of motion for all of the subjects was 10.4 degrees, but all of the subjects have very different range of motions. The smallest at 4.2 and 4.3 degrees (LH009 & LC002) and the largest are 13.9 and 16.8 degrees (AS006 & JD003). This was a very large movement for the knee, but because the knee was in a bent position for the plié closing, the knee can have a greater range of motion.

The last graph (Figure 33) to be reviewed for the abduction/adduction of the right knee was the relevé closing. All of the subject had a very small range of motion, just like in the traditional closing, and had an average range of motion of only 2.1 degrees for all of the subjects. With most of the subjects having almost no movement thought the tendu. Only HL005 has larger amount of movement and starts with adduction and moves to abduction from 60 to 80 percent and then back to adduction to end the tendu. This movement was not see in the other subjects.

The last section of data to be reviewed for the third position right leg was the rotation axis. The sphericity was not assumed so the Greenhouse – Geisser correction was used. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between plié and relevé, and not significant between traditional and relevé.

The graph (Figure 34) to be reviewed for the rotation axis was the traditional closing in third position. There was very little rotation for most of the subjects, only three of the subjects

have an arc to their graph line. This can be seen because the average range of motion for all of the subjects was 5.8 degrees. For the subjects (JD003, DR007, SW008,and LH009) that showed more knee rotation more than the others, the movement was internal rotation until about 40 percent of the tendu and then external rotation of the same magnitude until 80 percent of the tendu and they ended with no rotation to the end of the tendu. All of the other subjects had almost no rotation.

The next graph (Figure 35) to be reviewed for the rotation axis was the plié closing in third position. The knee rotations for the plié closing are not as smooth as the rotations for the traditional closing. All of the subjects have a higher degree of range of motion with 12.9 degrees being the average for all of the subjects. All of the subjects but HL005 they start with internal rotation and go into external rotation at 50 percent and go past their starting rotation until 70 percent and then hold steady until the end of the tendu. Only HL005 has rotation for the plié closing and not in the extension of the moving leg for the tendu. She has almost no knee rotation until 40 percent of the tendu and she goes into internal rotation until 80 percent and the ends the tendu by coming back to her base line rotation in external rotation.

The last graph (Figure 36) to be reviewed for the right knee in third position was the rotational axis with the relevé closing. The rotation of the knee with the relevé closing was more similar to the traditional closing than the plié closing. Most of the subjects have very little to no knee rotation during the tendu. The average range of motion for all of the subjects was almost the same as the traditional closing at 5.7 degrees. It the same subjects that had the high range of motion in the traditional closing that have the higher range of motion in the relevé closing. The knee rotation follows the same directions, stating with internal rotation and then to external rotation with no rotation at the end of the tendu.

From reviewing the statistics there was statistical significance between the traditional and plié closing and plié and relevé closing for all of the angles of the knee. This maybe because there was greater difference in the knee angles because the knee was bending in the plié were as the traditional and relevé closings are straight leg closings. There was only statistical significance between the traditional and the relevé closing for the knee angle of flexion/extension and this maybe because the subjects had a higher range of motion for the relevé closing than the traditional closing.

4.2.2 Left Knee

The first section of data to be reviewed for the third position left leg was the flexion/extension axis. There was statistical significance for this set of data. The sphericity was assumed. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between plié and relevé, and not significant between traditional and relevé.

The first graph (Figure 37) to be reviewed for the left knee in the flexion/extension axis was with the traditional closing. All of the subjects have the same overall movement excepted for one subject. They started in extension and held with a constant extension until about 60 percent and then closed with flexion to the same degree that they started with and held this degree until the end of the tendu. Only subject AS006 performed this move differently, she started with some extension and the went into flexion at 15 percent of the tendu and then back to extension at 40 percent of the tendu and held there until about 70 percent of the tendu where she went back in to flexion to end the tendu. The average range of motion for all of the subject was 9.2 degrees, but some had small range of motions like AC001 with 7.9 degrees. She did not have the same degree of hyperextension as she does with her right knee. The subject with the highest degree of range

of motion was subject HL005 with 13.6 degrees. She got to the same degree of extension as AC001, five degrees of extension (below the x-axis), but she had more range of motion overall. All of these range of motion are well within the normal range of motion for the body in the flexion/extension direction.

The next graph (Figure 38) to be reviewed was for the left knee in third position was for the plié closing in flexion/extension. The graph has the expected look for flexion/extension with the knee bending at the end of the movement. All of the subjects start out in extension and hold this extension as the foot moves out to the middle of the tendu, as they are bringing their leg back to their body for they go into flexion for the plié. The flexion for the plié was larger than the other closing, but understandable because the subjects are bending at the knee to perform the plié. The subjects have average range of motion for every one of 54.9 degrees. This was well within the normal range for this angle of the knee.

The last graph (Figure 39) to be reviewed for flexion/extension for the left knee was in the relevé closing. The relevé closing flexion/extension closely resembles the movement of the traditional closing, but there was more changing from extension to flexion in the relevé closing. This can most be seen in subjects AC001, HL005, and LM004. In AC001 she goes into extension and the event more extension at 30 percent, then into flexion at 40 percent and right back into a small amount of extension at 50 percent, then in to large amount of flexion at 60 percent of the tendu when she was bringing her moving leg back and at 85 percent she goes back to extension to reach the angle she started at. Subject LM004 does much the same as subject AC001, but without the first extra extension dip. And subject HL005 started 10 degrees higher than she did for traditional closing. She when into extension and back to flexion at 15 percent and back to extension at 35 percent, she repeated this until 80 percent and then had a large

amount of flexion and went above her starting angle. Most of the other subjects had the expected movement of extension followed by flexion to close the tendu.

The next set of graphs to be reviewed for third position left knee are abduction and adduction. There is statistical significance for this set of data. The sphericity was not assumed, so the Greenhouse – Geisser correction was used. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between plié and relevé, and not significant between traditional and relevé.

The graph (Figure 40) to be reviewed was third position left knee in traditional closing in the abduction/adduction axis. Most subject have very little range of motion in abduction/adduction which was to be expected because the normal range of motion was 5 degrees and the average for all of the subjects with the traditional closing was 1.7 degrees. All of the subjects start in the -0.5 to -3 degrees and end in this range too. Only subjects LH009 was out of this range, she starts and ends around 6 degrees. All the subject start with abduction and go into adduction between 50 and 60 percent of the tendu and hold this angle until the end of the tendu. A few subjects go back into abduction towards the end of the tendu (subjects AS006, HL005, and AC001).

The next graph (Figure 41) to be reviewed was third position left knee in the plié closing for abduction/adduction. The subjects for the plié closing showed many different versions of the knee angles. Only HL005 have very little range of motion with 3 degrees and she had abduction for the beginning and then adduction at 45 percent and held the same abduction until the end of the tendu. All of the other subjects had a large range of motion with an average range of motion for all for the subjects 8.9 degrees. This most evident with subject JD003, who had a range of

motion of 17.9 degrees. She did have same movement of the knee as the rest of the subject, which was almost no movement until 50 percent of the tendu, start of the plié closing, then abduction until 75 percent and then to adduction with change in degrees.

The last graph (Figure 42) to be reviewed was the relevé closing in third position for the left knee. Just like with the traditional closing the relevé closing had a small range of motion, with only 2.1 degrees as an average for all of the subjects. And the subjects are in the same range with starting between -0.5 to -2.3 degrees and ending between 0.4 to -2.3 degrees. Just like in the traditional closing only subject LH009 is out of this range with start around 6 degrees and ending at 6.8 degrees. The subjects again started with abduction and moved into adduction for the end of the tendu.

The set of graphs to look at for third position are of the left knee in the rotational axis. There was statistical significance for this set of data. The sphericity was assumed. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between plié and relevé, and not significant between traditional and relevé.

The first graph (Figure 43) to be reviewed was the traditional closing of the left knee in third position rotational axis. The subject have the same overall movement which was internal rotation followed by external rotation. That average range of motion for all of the subjects was 5 .8 degrees, which was in the normal range for rotation. Some subjects had large range of motion than others, but this was to be expected as everyone moves slightly differently.

The next graph (Figure 44) to be reviewed was the plié closing in third position. This graph had a different look than that of the traditional closing. The subjects start in internal rotation and then to external rotation, just like in the traditional closing, but they do more

external rotation than the internal rotation they started with. And during the plié closing they go back to internal rotation followed by external rotation aging. But they all to come back to their starting angle of rotation except for subject AS006. As a group the average range of motion was 12.6 degrees, which higher than the normal range of motion of 10 degrees.

The last graph (Figure 45) to be reviewed was the relevé closing in third position for the left knee. The rotations for the relevé closing are a little jagged than the other closing, but they have the same overall motion, internal rotation followed by external rotation. The range of motion is also smaller at 5.7 degrees for an average for all of the subjects.

From reviewing the statistics there was statistical significance between the traditional and plié closing and plié and relevé closing for all of the angles of the knee. This maybe because there was greater difference in the knee angles because the knee was bending in the plié were as the traditional and relevé closings are straight leg closings. There was only statistical significance between the traditional and the relevé closing for the knee angle of abduction/adduction and this maybe because the subjects had a higher range of motion for the relevé closing than the traditional closing.

4.3 Fifth Position

The final foot position that a dancer will lean is fifth position. Fifth position is when the feet are completely crossed, so that the heel of one foot is teaching the toe of the other foot. This is considered the ideal position of the feet. At the University of South Florida School Dance the students are taught to perform in a comfortable fifth position. In the comfortable fifth position, the dancer only turns out their feet as far as they comfortably can to cross their feet. This is how the subjects performed their fifth position tendus.

4.3.1 Right Knee

The first section of data to be reviewed for the fifth position right leg was in the flexion/extension axis. There was statistical significance for this set of data. The sphericity was not assumed so the Greenhouse – Geisser correction was used. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between traditional and relevé, but there was not statistical significances between plié and relevé.

The graph (Figure 46) to be reviewed was fifth position right knee flexion/extension with the traditional closing. All of the subjects have the same movement for the tendu in fifth position in the flexion/extension. They all start in extension as they move their leg out, they hold a constant extension through this move and as they start to bring their leg back to their body they go into the flexion at about 75 percent of the tendu in the same degree that they extended their leg. For example BW010 starts at 7 degrees then moves in extension to at -0.2 degrees and then in to flexion and back to 7 degrees. All of the subjects but AC001, LM004, and HL005 stay above the neural (zero line of the graph), so they never cross into extension. Then most of the subject held this degrees until the end of the tendu, but a few of the subjects when back into some extension to end the tendu. All of the subjects had an average range of motion of 12.03 degrees which was higher than first and third position, but well within the normal range of motion. Subject AC001 was once aging in hyperextension, just like in first and third position.

The next graph (Figure 47) to be reviewed was fifth position right knee flexion/extension with the plié closing. The subjects have the movement that was to be expected with the knee bending at the end of the tendu. They start in extension as they move they leg way from the body to perform the tendu. Holing the this degree of extension until 50 percent of the tendu when the

plié is started, then move into flexion higher than the starting point and then back in to extension after reaching the bottom of the plié, but never crossing the line back into true extension. An example of this was subject LH009 starting at 29 degrees of flexion moving in extension to 5 degrees of flexion then up to 61 degrees in flexion and then to 32 degrees of flexion. Still only subjects AC001, LM004, and HL005 move into true extension by crossing the zero line of the graph. AC001 was still in hyperextension going from 6 degrees of flexion to -14 degrees in true extension and then up of 42 degrees of flexion and down in extension to 6.5 degrees of flexion to end the tendu. The overall average range of motion for all of the subjects was 54.6 degrees.

The last graph (Figure 48) to be reviewed for flexion/extension in fifth position right knee with the relevé closing. The movement of the subjects for the relevé closing was not as smooth as they had in the traditional closing. Some of the subjects start to go back into flexion before 50 percent of the tendu (about 40 percent) while the rest start the flexion well past 50 percent of the tendu (60 percent). Starting the flexion at 60 percent was more in line with what the subjects should be doing for closing to the relevé. In the relevé they should not be bending their leg as they go up into the relevé and what little flexion they have should only happen at the end of end of the tendu closing. Just like in the traditional and plié closing subject AC001, LM004, and HL005 are the only that go into true extension by crossing the zero line of the graph, all of the others move in the direction of extension when they are extending their legs, but always stay in on the flexion side of the graph. AC001 was still in hyperextension starting at -4.2 degrees in extension and moving to -14 degrees of extension and then flexion up to -2.2 degrees of extension at 80 percent of the tendu and ending a -3.8 degrees.

The next set of graph to be reviewed was fifth position right knee in the abduction/adduction axis. There was statistical significance for this set of data. The sphericity

was not assumed so the Greenhouse – Geisser correction was used. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between traditional and relevé, but there was not statistical significances between plié and relevé.

The first graph (Figure 49) to be reviewed was for abduction/adduction for fifth position on the right knee with the traditional closing. All of the subject have a very small range of motion for in the abduction/adduction axis which was to be expected. The average range of motion for all of the subject was only 1.9 degrees. This was such a small range that it was almost no movement. Form looking at the graph all of the subjects but LH009 are in the range of the graph with them starting and ending at the same degree. This range was 2.8 degrees (abduction) to -2.8 degrees (adduction). Subject was in abduction at 6 degrees to start and ending at 6.5 degrees. One interesting subject was HL005, she starts out in adduction (-0.3 degrees) hold there until about 70 percent of the tendu and then goes into abduction to 2 degrees at 90 percent and ends with 1.12 degrees of abduction.

The next graph (Figure 50) to be reviewed was fifth position abduction/adduction of the right knee with the plié closing. The subjects show more abduction to close to the plié and this was because the knee was bent. Only subject LC002 have about the same range of motion as the traditional closing, about 4 degrees, and stay in the range of movement. She starts in adduction (-3 degrees) and holds there until 60 percent of the tendu and move in the direction of abduction, but only reaching 0.4 degrees of abduction and then going back her starting point to end the tendu. All of the other subjects have a very different movement to their plié closing. They start in abduction and move in the direction of adduction, but only LM004, JD003, and HL005 go into adduction, and at 50 percent of the tendu they move in to abduction and back to the direction of

adduction at 80 percent. This was a change of about 10 degrees and they can achieve 10 degrees of abduction because the knee was bent.

The last graph (Figure 51) to be reviewed for fifth position right knee was abduction/adduction with the relevé closing. The relevé closing just like the traditional closing had very little movement in the abduction/adduction axis. There was only 2.8 degrees of range of motion for an average for all of the subjects. This was slightly higher than the traditional, but eight degrees less than the plié closing. This means that there was almost no movement in the knee at this axis which was to be expected. All of the subjects but LH009 are in the same range for starting and ending just like in the traditional closing (2.8 to -2.8 degrees). LH009 was in abduction starting at 6 degrees and ending at 6.7 degrees. In general the subjects move from abduction to adduction, but movement was so small it was almost a straight line.

The last set of graphs to be reviewed for the right knee was fifth position in the rotational axis. There was statistical significance for this set of data. The sphericity was assumed. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between traditional and relevé, but there was not statistical significances between plié and relevé.

The first graph (Figure 52) to be reviewed for fifth position right knee was the rotational axis was with the traditional closing. All of the rotation that taking place in the subjects are in the external rotation direction of the graph. The subject show their knee moving in internal rotation until about 50 percent of the tendu and then return in external rotation, but they never cross the zero axis into internal rotation. Their average range of motion for all of the subjects was 6.5 degrees and this in the middle of what was the normal range of motion for the knee in rotation.

A few subjects have almost no movement for duration of the tendu (LC002, LM004, and AS006).

The next graph (Figure 53) to be reviewed for fifth position right knee was the rotation with the plié closing. Again all of the subjects are in external rotation for the entire duration of the tendu. The subjects had a higher average range of motion for the plié than the traditional closing, it was 13.3 degrees. They had a different movement starting in the internal direction for about 10 degrees and then moving in the external rotation direction for about 13 degrees and holding this degree of external rotation until the end of the tendu.

The last graph (Figure 54) to be reviewed for fifth position right knee was rotation with the relevé closing. All of the subjects are in the external rotation for the entire tendu. Some of the subject had almost no rotation like LM004, LC002, and HL005. All of the subjects had an average range of motion of 5.9 degrees which was less then there traditional and plié closings. Of the subjects that showed movement in the rotation axis the movement was to start in internal rotation and at 50 percent of the tendu move into external rotation, but they never crossed the zero line into true internal rotation.

From reviewing the statistics there was statistical significance between the traditional and plié closing and plié and relevé closing for all of the angles of the knee. This maybe because there was greater difference in the knee angles because the knee was bending in the plié were as the traditional and relevé closings are straight leg closings. There was no statistical significance between the traditional and the relevé closing for any of the angles of the knee and this maybe because these are both straight leg closings.

4.3.2 Left Knee

The first section of data to be reviewed for the fifth position left leg was in the flexion/extension axis. There was statistical significance for this set of data. The sphericity was assumed. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between traditional and relevé, but there was not statistical significances between plié and relevé.

The first graph (Figure 55) to be reviewed was the fifth position left knee in the flexion/extension axis with the traditional closing. For the left knee in fifth position the graph was not as smooth as with the right knee. All of the subjects have but AC001 have the same movement, starting in flexion and moving in extension an average of 8.5 degrees and hold there until about 50 percent of the tendu when they move in flexion back up about an average of 9 degrees and then back down in extension to their starting point. Only subjects DJ003, LM004, and HL005 cross the neutral line into extension. Subject AC001 did not follow any of the movement of the other subjects, she started at -5 degrees of extension and held there until the end of the tendu and only had a range of motion of 2.8 degrees were all the subjects had an average range of motion of 10.3 degrees.

The next graph (Figure 56) to be reviewed was fifth position left knee in the flexion/extension axis with the plié closing. In the plié closing all of the subjects follow the same movement of going into extension and back into flexion an average of 53.6 degrees at 50 percent of the tendu and then going back to their starting degree of flexion. The subjects have been crossing into extension still cross into extension with AC001 having the most extension.

The last graph (Figure 57) to be reviewed was fifth position left knee in flexion/extension axis with the relevé closing. All of the subject behave in about the same manner with going into extension and back into flexion at 60 percent of the tendu and then came back to their starting degree of flexion. Half of the subject crossed the neutral line with AC001 going into the most extension of all of the subjects.

The next section of data to be reviewed for the fifth position left leg was in the abduction/adduction axis. There was statistical significance for this set of data. The sphericity was not assumed, so the Greenhouse – Geisser correction was used. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between traditional and relevé, but there was not statistical significances between plié and relevé.

The first graph (Figure 58) to be reviewed was fifth position left knee in the abduction/adduction axis with traditional closing. The overall movement of the subject was very small with only 1.8 degrees of range of motion for all of the subjects as an average. All of the subject, but LH009 are in the 0.8 degrees of abduction to -3.3 degrees of adduction and this was the same rage that they end their tendu in. LH009 starts and ends at 6.4 degrees. Of the movement that the subjects do have it was an abduction to start the tendu and at 50 percent go into adduction.

The next graph (Figure 59) to be reviewed was fifth position left knee in the abduction/adduction axis with the plié closing. Only subject HL005 was able to stay around the neutral line and had a range of motion of 3 degrees, but mainly staying in abduction. All of the other used more of their abduction to perform the tendu. They held their starting degree of abduction until 50 percent of the tendu and then abducted and average of 9.4 degrees and the

returned to their starting abduction in adduction. Only BW010 did not return to her starting degree of abduction.

The first graph (Figure 60) to be reviewed was fifth position left knee in the abduction/adduction axis with traditional closing. The overall movement of the subject was very small with only 1.8 degrees of range of motion for all of the subjects as an average. All of the subject, but LH009 are in the 0.4 degrees of abduction to -2.8 degrees of adduction and this was the same rage that they end their tendu in. LH009 starts at 6.5 and ends at 7.2 degrees. Of the movement that the subjects do have it was an abduction to start the tendu and at 50 percent go into adduction.

The last section of data to be reviewed for the fifth position left leg was in the rotational axis. There was statistical significance for this set of data. The sphericity was assumed. The pairwise comparison shows there was statistical significance $p < 0.05$ between traditional and plié, between traditional and relevé, but there was not statistical significances between plié and relevé.

The first graph (Figure 61) to be reviewed was fifth position left knee in the rotational axis with the traditional closing. The subjects had the same movement for the rotation of the knee stating with internal rotation and going into external rotation at 50 of the tendu, but all of the subjects are on the external rotation side of the neutral line. Their average range of motion for all of the subject 6.3 degrees, but some have lest like AC001 (3.2degrees) and LM004 (4.7 degrees). DR007 and SW008 at the greatest at 9.24 and 9.39 degrees respectively.

The next graph (Figure 62) to be reviewed was fifth position left knee in the rotational axis with the plié closing. The knee rotations for the plié closing are not as smooth as the

traditional closing, but had the same movement. Starting in internal rotation and moving to external rotation at 50 percent of the tendu, but JD003 and HL005 went back into internal rotation at about 65 percent and then closed with external rotation at the end of the tendu. But in the plié closing the subjects has a higher range of motion of 13.2 degrees for an average for all of the subjects. The subjects were still in the external rotation range of the graph.

The last graph (Figure 63) to be reviewed was fifth position left knee in the rotational axis with the relevé closing. The subjects has a smaller range of motion for the relevé closing (6.5 degrees) than the plié closing. But still have the same movement with internal rotation and moving to external rotation now at 70 percent instead of 50 percent like traditional and plié. And again all of the movement was the external range of the graph.

From reviewing the statistics there was statistical significance between the traditional and plié closing and plié and relevé closing for all of the angles of the knee. This maybe because there was greater difference in the knee angles because the knee was bending in the plié were as the traditional and relevé closings are straight leg closings. There was no statistical significance between the traditional and the relevé closing for any of the angles of the knee and this maybe because these are both straight leg closings.

4.4 Comparisons of the Closings

From the data it was found that for all of the axis and closing positions, there was statistical significance between the traditional closing and plié closing and between the plié closing to the relevé closing. This can be attributed to the fact in the traditional and relevé closings the knee was kept straight and in the plié closing the knee was bending. The data did not have the same result for comparing the traditional closing to the relevé closing. Only for first

position right knee in flexion/extension, first position left knee flexion/extension; third position right knee flexion/extension and third position right knee abduction/adduction had statistical significance. All of the other angles for the right and left knee showed no statistical significance. This can be attributed to the fact in both of these closings the knee was kept straight, the only difference was that in the traditional closing the feet stay on the ground and in the plié the heels of both feet come off the ground. The thought behind having the dancers close to the relevé in comparison to the traditional closing was that the dancer needs room to bring their moving leg back to their body and in class they are taught to lift their hips to make this room.

Some interesting results seen in the data for the plié was the how the angles for all of the directions were larger than the traditional and relevé closings. The angles were as expected in the flexion and extension direction because the knee was bending for the plié and was not supposed to be bending in the traditional and relevé closing. In the abduction and the adduction angles the subjects had a larger range of motion than that of the traditional and relevé closing. This may be due to the subjects using the abduction of the knee bent to hold the foot turned out in trying to keep the proper turnout for each of the 1^{st}, 3^{rd}, and 5^{th} positions. Although one subject on each the right and the left side had far less abduction than the other subjects. This was subject LC002 for the right knee and subject HL005 for the left knee and this was for all of the positions. LC002 was also able to return to adduction at the end of the tendu when closing to the plié and no other subject was able to do this for the plié closing.

The interesting result for the traditional and the relevé closing was that the dancers bend their knee slightly for the closing on the way the moving leg was coming back to the body at the starting point. The thought from the dance community and stated in the introduction was for the moving leg to extend away from the body for the start of the tendu and then on the way back to

the body the moving leg would stay in extension for this part of the tendu. From looking at the data it can be seen that subjects bent their moving leg for the end of the tendu, showing that the dancers are moving their leg to accomplish the movement in a way which the dance instructor did not think they were doing. Due the degree in which the subjects bent their leg it was hard to see this bending of the knee with the naked eye. Another interesting result was for subject HL005 in first position on the right knee, she had almost no range of motion in the traditional closings appearing as almost flat line on the graph and in third position on the right knee she had almost no range of motion in the traditional and relevé closings appearing as almost flat line on the graph, this may be due to the muscle control that this subject has in her knee.

The interesting result for the relevé closing was very similar to the traditional closing, but although the relevé closing has the same overall shape of the graphs in general the lines on the graph were more jagged than the traditional closing. This may be due the fact the subjects were rising to their toes to close to the relevé and could have some moving more to keep their body stable as they rise.

There were only a few of the references reviewed for the thesis. The Bennell *et al* study looked into hip and ankle range of motion and the thesis studied the range of motion of the knee. Watkins *et al* believed that the dancers were able to get greater turnout because they were bracing their legs against each other for fifth position, although this could not be proven in the current thesis, the some subjects would bend their legs to achieve fifth position and then quickly straighten their leg and brace to keep the legs straight. In the Barnes *et al* study of the grand plié fond that the External Longitudinal Rotation was greater at the bottom of the grand plié and it was also seen in this thesis that there was great range of motion in the rotational axis for the plié closing than for the traditional and relevé.

4.5 Observations

Of the videos collected in the study one can see some of the dancers trying to lift their hip to the point one almost losses her balance. Then with closing to the relevé this would give the dancers the space they need to bring their moving leg back to center of their body to complete the closing to first, third, or fifth. Even with this extra room for the dancers to close there was still no significant change in their knee angles. This was understandable when looking at the difference in the average range of motion between the traditional and the relevé where the change is never over 0.7 degrees for rotation and never over 0.4 degrees for abduction/adduction. The dancers did look in better form as they closed to the relevé over the traditional from looking at the video. This was seen in the subject AC001 in fifth position. Some of the dancers still had some balance issues, but this could be from not have a strong core as stated by the Physical Therapist (PT). Also for subject AC001 the videos and Visual 3D model (Figure 64) showed her hyperextension which can be seen in the graphs of flexion/extension in Chapter 3 of this thesis.

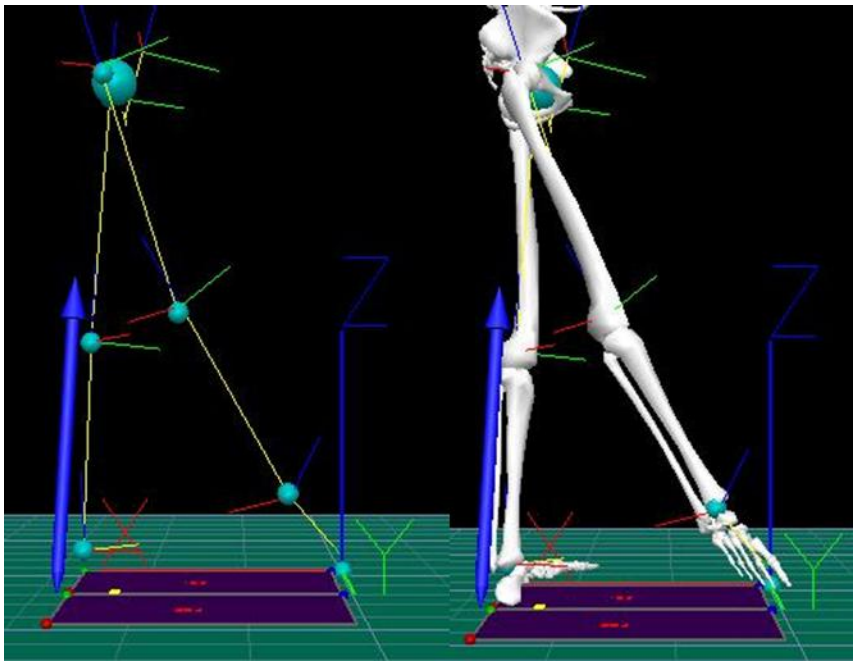

Figure 64: Hyperextension of Subject AC001 from Visual 3D

One of the things the PT noted was that the dancers do not have the room for moving her leg back into their body for the traditional closing. This was also the observation of the dance teacher from many years as a performer and instructor. Dance instructors are always teaching the dance students to raise their hips when closing during the five positions of ballet. By closing to the relevé it gave the dancer the room needed to bring their moving leg back without adjusting their hip or knees. Although because the data showed no significant difference between traditional and relevé for most of the closing this could be because there is no difference. A possible explanation for this was that dancers were moving their knees the same as they do for the traditional closing even though they have the room to bring their moving leg back without adjusting the knee with the relevé closing. This would be reviewed with the help of a PT and talking to the dancers about how they move in each of the closings. With the dancers in fifth position they are engaging the abductors of the hip to hold their leg in a turned out position and it was their hip adductors that help in moving the leg back to the body to close the tendu.

The other thought for changing the closing was to have the dancers closed to the plié. A plié is a bend of the knee and for the study the subjects started the plié as they were bringing their moving leg back to their body and would not re-straighten their knee. By not having the dancers re-straighten their knee then they would also have the room to close the moving leg back to their body because both of their legs are bent. By having the dancers legs bent they cannot do the adjustments at the knee that they may do to give the appearance of closing with a straight leg. The dance instructor noted that she had only seen two students in all of her years of teaching that did not do something to get the straight leg closing and that was because they were bow legged which as stated by Neumann is 180 degrees or greater[13]. All of the subjects in all of the closings have very little range of motion for the abduction/adduction for the traditional and relevé closings, generally two degrees or less as an average, and around ten degrees for the plié closings. The higher range of motion in the plié closing was because the dancers have their knees bent. This was outside the normal range of motion for the abduction/adduction of the knee, but poses no threat to the dancer because it was when bending the knee results in extra degrees of freedom for the joint. Because the knee had more degrees of freedom with the knee bent than with the knee straight the angles were larger for the plié than for all three different axis than for the traditional and relevé closings.

4.6 Limitations

As with all studies there are limitations in the ability to collect the data. Some of the limitations with this study were in the motion capture. There could be some amount of error in the placement of the markers on the each subject. There could also be skin movement that is picked up as marker movement. Also with the legs crossing one another for the third and fifth position, closing the markers on the medial knee were at some points obscured by the other leg.

In the post-processing the fill gaps of above 10 frames could have some error in using the partner marker as a guide for the trajectory.

CHAPTER 5: CONCLUSION

Dance is an art form that takes many years to perfect and over these years the dancers can develop their individual adaptations while performing these standardized positions that can cause injury to their bodies. This thesis looked at the knee angles of ten healthy dance students from the University of South Florida to analyze their knee angles changes as they closed to the plié and relevé in comparison to the traditional closing as they closed to first, third, and fifth position. The angles that were looked are flexion/extension, the x-axis, abduction/adduction, the y-axis, and rotation, the z-axis.

From this study one cannot prove that the traditional method of closing to first, third, and fifth position is harmful to the human body because dancers having been performing these moves since the 17^{th} century. It can be seen that changing the way a dancer closes the tendu does change the way the knee behaves. The thought is that changing the closing to the relevé or plié would give the dancer's moving leg more room to finish the closing without have to change the position of the knee to get the moving leg back to the body. It was also seen in the videos that some of the dancers to first get into fifth position would first plié and then rapidly lock their knees in extension and brace their legs against each other resulting in their whole body rising up quickly. This is because they do not have the ability to keep their legs fully rotated in the turn out position and also cross their legs completely like the fifth position requires.

The plié had the largest range of motion for all of the closing studied and for all of the angles analyzed. This range of motion gives the dancers room to move their moving leg in all

directions. The plié also allows the dancer to bring their leg back to the body with more of a bend even though the subjects did bend their legs slightly for the other closing. With this slight bend of the leg for the traditional and relevé closings the subjects were performing the movements but not how the dance instructor thought they were supposed to be closing. This could mean that the subjects were compensating for control in bending their leg

Each dancer had their own individualized way of performing the closings. Overall they completed the tendu with the same general movement but each individual subject had slight differences in the movement that was seen on the graphs. These movements and positions for closing are very standardized throughout the dance community. A general idea in Dance as expressed by the dance instructor was the idea of perfection in all aspects of dance which includes each of the positions studied. When a dance student's body cannot reach these ideal images of the movement they are trying to accomplish, they may begin to start adjusting different aspects of their body to attempt to reach this ideal image which is to achieve perfection. All of the adjustments by the dancers seen on the graphs were surprising to the dance instructor since these variations are subtle and difficult to see with the naked eye. Each subject had a different starting position to complete these standardized movements. This created a larger overall range of movement

The dancers observed the video with the stick figure during data collection. The motion analysis results were not shared with the individual dancers but were reviewed by the dance instructor who noted the variations in how the dancers performed the movements. This would be helpful for the dance student to see how they move in comparison to what ideal image they have of their movements. The dancer has an ideal image in their brain of what each movement

should look like. For correction of their compensation in their knee angles, it would be helpful to prevent injury to their lower limbs and reduce stress on their joints which allows them to be dancing for more years.

5.1 Future Work

Some future work for this study is look at the video and graphs of all of the dancers with a Physical Therapist and/or Physicians to determine what the muscle skeletal system is doing in these closings. Look at closing to the side and back to see if the dancers are most stable in these closings. The tendu is also done to the side and the back of the body and could be interesting to see how the angles of the knee change in these closings and it the dancers are more or less stable in their movements.

An important future work could be to starting looking into the whole kinetic chain. The kinetic chain is the ankles to the knees to the hips and while this study only looked at the knee. The rest of chain is important because they are all connected and the actions of one joint can affect the other joints in the chain. Some the could be seen in the videos in that some subject lifted the hip of the moving leg for closing the tendu and it could be interesting to investigate what the subject was doing.

Looking at the forces on the knee could also help in understanding the moments and toques that is happening at the knee closing to the traditional closing and see if and how it changes when closing to the plié and relevé. One of the limitation of the current set up of the lab the study was performed in was this data could not be collected even with the force plates. The force plates require for only one foot being on the force at a time and when closing to the third

and fifth positions the feet need to be touching. May be using a different set up for the forces plates or force sensors that can be placed in the shoes of the dancers could possibly yield this type of data.

This study could be a teaching tool for dance instructors and their students to give them qualitative feedback on their dance movements. This could help in their dance education and possibly for those who continue dance into professional dance companies.

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APPENDICES

Appendix A: Pipeline Code From Visual 3D

Front left event:

```
Event_Delete
/EVENT_NAME=Start
! /EVENT_SEQUENCE=
! /EXCLUDE_EVENTS=
! /TIME=
;

Metric_Maximum
/RESULT_METRIC_NAME=max
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE
! /RESULT_METRIC_FOLDER=PROCESSED
/SIGNAL_TYPES=TARGET
/SIGNAL_NAMES=LTOE1
! /SIGNAL_FOLDER=ORIGINAL
/SIGNAL_COMPONENTS=X
/EVENT_SEQUENCE=
/EXCLUDE_EVENTS=
/GENERATE_MEAN_AND_STDDEV=FASLE
/APPEND_TO_EXISTING_VALUES=FALSE
/CREATE_GLOBAL_MAXIMUM=TRUE
;

Event_Threshold
/SIGNAL_TYPES=TARGET
/SIGNAL_NAMES=LTOE1
/SIGNAL_FOLDER=ORIGINAL
/EVENT_NAME=Start
/SELECT_X=TRUE
/SELECT_Y=FALSE
/SELECT_Z=FALSE
/SELECT_RESIDUAL=FALSE
/THRESHOLD=(METRIC::PROCESSED::LTOE1max-0.04)
/FRAME_WINDOW=20
! /FRAME_OFFSET=0
! /ASCENDING=FALSE
/DESCENDING=TRUE
! /ENSURE_RANGE_FRAMES_BEFORE_THRESHOLD_CROSSING=FALSE
/ENSURE_RANGE_FRAMES_AFTER_THRESHOLD_CROSSING=TRUE
! /START_AT_EVENT=
! /END_AT_EVENT=
```

Appendix A (Continued)

```
! /EVENT_INSTANCE=
;


Event_Explicit
/EVENT_NAME=Start
!/FRAME=
/TIME=EVENT_LABEL::ORIGINAL::Start[3]+(EVENT_LABEL::ORIGINAL::Start[3]-
EVENT_LABEL::ORIGINAL::Start[2])
;
```

Front right event:

```
Event_Delete
/EVENT_NAME=Start
! /EVENT_SEQUENCE=
! /EXCLUDE_EVENTS=
! /TIME=
;


Metric_Maximum
/RESULT_METRIC_NAME=max
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE
! /RESULT_METRIC_FOLDER=PROCESSED
/SIGNAL_TYPES=TARGET
/SIGNAL_NAMES=RTOE1
! /SIGNAL_FOLDER=ORIGINAL
/SIGNAL_COMPONENTS=X
/EVENT_SEQUENCE=
/EXCLUDE_EVENTS=
/GENERATE_MEAN_AND_STDDEV=FASLE
/APPEND_TO_EXISTING_VALUES=FALSE
/CREATE_GLOBAL_MAXIMUM=TRUE
Event_Threshold
/SIGNAL_TYPES=TARGET
/SIGNAL_NAMES=RTOE1
/SIGNAL_FOLDER=ORIGINAL
/EVENT_NAME=Start
/SELECT_X=TRUE
/SELECT_Y=FALSE
/SELECT_Z=FALSE
```

Appendix A (Continued)

```
/SELECT_RESIDUAL=FALSE
/THRESHOLD=(METRIC::PROCESSED::RTOE1max-0.07)
/FRAME_WINDOW=20
! /FRAME_OFFSET=0
! /ASCENDING=FALSE
/DESCENDING=TRUE
! /ENSURE_RANGE_FRAMES_BEFORE_THRESHOLD_CROSSING=FALSE
/ENSURE_RANGE_FRAMES_AFTER_THRESHOLD_CROSSING=TRUE
! /START_AT_EVENT=
! /END_AT_EVENT=
! /EVENT_INSTANCE=
;


Event_Explicit
/EVENT_NAME=Start
!/FRAME=
/TIME=EVENT_LABEL::ORIGINAL::Start[3]+(EVENT_LABEL::ORIGINAL::Start[3]-
EVENT_LABEL::ORIGINAL::Start[2])
;
```

Knee Angle pipeline:

```
Compute_Model_Based_Data
/RESULT_NAME=Left Knee Angle
/FUNCTION=JOINT_ANGLE
/SEGMENT=LTH
/REFERENCE_SEGMENT=LSK
/RESOLUTION_COORDINATE_SYSTEM=
! /USE_CARDAN_SEQUENCE=FALSE
! /NORMALIZATION=FALSE
! /NORMALIZATION_METHOD=
! /NORMALIZATION_METRIC=
! /NEGATEX=FALSE
! /NEGATEY=FALSE
! /NEGATEZ=FALSE
! /AXIS1=X
! /AXIS2=Y
! /AXIS3=Z
;
```

Appendix A (Continued)

```
Compute_Model_Based_Data
/RESULT_NAME=Right Knee Angle
/FUNCTION=JOINT_ANGLE
/SEGMENT=RTH
/REFERENCE_SEGMENT=RSK
/RESOLUTION_COORDINATE_SYSTEM=
! /USE_CARDAN_SEQUENCE=FALSE
! /NORMALIZATION=FALSE
! /NORMALIZATION_METHOD=
! /NORMALIZATION_METRIC=
! /NEGATEX=FALSE
! /NEGATEY=FALSE
! /NEGATEZ=FALSE
! /AXIS1=X
! /AXIS2=Y
! /AXIS3=Z
;
```

Left range of motion:

```
Metric_Maximum
/RESULT_METRIC_NAME=max
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE
! /RESULT_METRIC_FOLDER=PROCESSED
/SIGNAL_TYPES=LINK_MODEL_BASED
/SIGNAL_NAMES=LKNEE ANGLE
/SIGNAL_FOLDER=ORIGINAL
/SIGNAL_COMPONENTS=ALL_COMPONENTS
/EVENT_SEQUENCE=Start+Start
/EXCLUDE_EVENTS=
/GENERATE_MEAN_AND_STDDEV=FALSE
! /APPEND_TO_EXISTING_VALUES=FALSE
! /CREATE_GLOBAL_MAXIMUM=FALSE
;
```

```
Metric_Minimum

/RESULT_METRIC_NAME=min
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE
! /RESULT_METRIC_FOLDER=PROCESSED
/SIGNAL_TYPES=LINK_MODEL_BASED
/SIGNAL_NAMES=LKNEE ANGLE
```

Appendix A (Continued)

```
/SIGNAL_FOLDER=ORIGINAL
/SIGNAL_COMPONENTS=ALL_COMPONENTS
/EVENT_SEQUENCE=Start+Start
/EXCLUDE_EVENTS=
/GENERATE_MEAN_AND_STDDEV=FALSE
! /APPEND_TO_EXISTING_VALUES=FALSE
! /CREATE_GLOBAL_MAXIMUM=FALSE
;

Evaluate_Expression
/EXPRESSION=METRIC::PROCESSED::LKNEE ANGLEmax-
METRIC::PROCESSED::LKNEE ANGLEmin
/RESULT_NAME=LKneeROM
/RESULT_TYPE=METRIC
! /RESULT_FOLDER=PROCESSED
;
```

Right range of motion:

```
Metric_Maximum
/RESULT_METRIC_NAME=max
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE
! /RESULT_METRIC_FOLDER=PROCESSED
/SIGNAL_TYPES=LINK_MODEL_BASED
/SIGNAL_NAMES=RKNEE ANGLE
/SIGNAL_FOLDER=ORIGINAL
/SIGNAL_COMPONENTS=ALL_COMPONENTS
/EVENT_SEQUENCE=Start+Start
/EXCLUDE_EVENTS=
/GENERATE_MEAN_AND_STDDEV=FALSE
! /APPEND_TO_EXISTING_VALUES=FALSE
! /CREATE_GLOBAL_MAXIMUM=FALSE
;

Metric_Minimum
/RESULT_METRIC_NAME=min
/APPLY_AS_SUFFIX_TO_SIGNAL_NAME=TRUE
! /RESULT_METRIC_FOLDER=PROCESSED
/SIGNAL_TYPES=LINK_MODEL_BASED
/SIGNAL_NAMES=RKNEE ANGLE
```

Appendix A (Continued)

```
/SIGNAL_FOLDER=ORIGINAL
/SIGNAL_COMPONENTS=ALL_COMPONENTS
/EVENT_SEQUENCE=Start+Start
/EXCLUDE_EVENTS=
/GENERATE_MEAN_AND_STDDEV=FALSE
! /APPEND_TO_EXISTING_VALUES=FALSE
! /CREATE_GLOBAL_MAXIMUM=FALSE
;

Evaluate_Expression
/EXPRESSION=METRIC::PROCESSED::RKNEE ANGLEmax-
METRIC::PROCESSED::RKNEE ANGLEmin
/RESULT_NAME=RKneeROM
/RESULT_TYPE=METRIC
! /RESULT_FOLDER=PROCESSED
;
```

Appendix B: Data Collection Sheet

Dance Study Data Collection Checklist

Subject ID: _____ Name: _____ Date: _____

Age: _____ Height (m):_____ Weight (kg):_____

ASI Distance (mm):_____ Knee Distance (mm): R _____ L_____

- ❑ Subject sign informed consent
- ❑ Dancers self-directed warm up
- ❑ Measure and record subject measurements
- ❑ Attach marker set

Torso	Right Leg	Left Leg
❑ RHSO	❑ RASI	❑ LASI
❑ LSHO	❑ RPSI	❑ LPSI
❑ CLAV	❑ RTHI	❑ LTHI
❑ STRN	❑ RKNL	❑ LKNL
❑ C7	❑ RKNM	❑ LKNM
❑ T10	❑ RTIB	❑ LTIB
❑ RBAK	❑ RAKL	❑ LAKL
	❑ RAKM	❑ LAKM
	❑ RTOE1	❑ LTOE1
	❑ RTOE5	❑ LTOE5

- ❑ **Calibrate cameras and force plates**
- ❑ **Static Trial**
- ❑ **Auto Label**

Trials: The subjects will perform the tendu with the right and left foot to the front, side, and back three times for each trial. These movements will be done in first, third and fifth positions. For the third and fifth positions, the working foot will be the forward foot for the closing of the move. And for the side footwork the dancer will change as they close, so they will close to the front and then to the back of the supporting foot. The trials will start with the traditional movement followed by the two modified movements for the ending, one a releve and the other a demi plié without re-straightening.

Appendix B (Continued)

Dance Study Data Collection Checklist

First Position Tendu: First_(F/S/B)_(R/L)_#

❑ Right Front ❑ Right Side ❑ Right Back
❑ Left Front ❑ Left Side ❑ Left Back

Third Position Tendu: Third_(F/S/B)_(R/L)

❑ Right Front ❑ Right Side ❑ Right Back
❑ Left Front ❑ Left Side ❑ Left Back

Fifth Position Tendu : Fifth_(F/S/B)_(R/L)

❑ Right Front ❑ Right Side ❑ Right Back
❑ Left Front ❑ Left Side ❑ Left Back

First Position Tendu with releve: First_Releve_(F/S/B)_(R/L)_#Note might have

❑ *Right Front* ❑ *Right Side* ❑ *Right Back*
❑ *Left Front* ❑ *Left Side* ❑ *Left Back*

Third Position Tendu with releve: Third_Releve_(F/S/B)_(R/L)

❑ Right Front ❑ Right Side ❑ Right Back
❑ Left Front ❑ Left Side ❑ Left Back

Fifth Position Tendu with releve : Fifth_Releve(F/S/B)_(R/L)

❑ Right Front ❑ Right Side ❑ Right Back
❑ Left Front ❑ Left Side ❑ Left Back

First Position Tendu with plié: First_Plié_(F/S/B)_(R/L) Note might have

❑ *Right Front* ❑ *Right Side* ❑ *Right Back*
❑ *Left Front* ❑ *Left Side* ❑ *Left Back*

Third Position Tendu with plié: Third_Plié_(F/S/B)_(R/L)

❑ Right Front ❑ Right Side ❑ Right Back
❑ Left Front ❑ Left Side ❑ Left Back

Fifth Position Tendu with plié: Fifth_Plié_(F/S/B)_(R/L)

❑ Right Front ❑ Right Side ❑ Right Back
❑ Left Front ❑ Left Side ❑ Left Back

Comments:

Appendix C: Matlab Code

The following Matlab code was to make the rotational equation.

```
clc
syms a b g

disp(' rotation matrix about X axis')
Rz=[cos(a) -sin(a) 0;sin(a) cos(a) 0;0 0 1]
disp(' rotation matrix about Y axis')
Ry=[cos(b) 0 sin(b);0 1 0;-sin(b) 0 cos(b)]
disp(' rotation matrix about Z axis')
Rx=[1 0 0;0 cos(g) -sin(g);0 sin(g) cos(g)]
disp('over all  rotation matrix ')
Rxyz=Rx*Ry*Rz %rotation in X-Y-Z for Euler angles
```