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Genu Recurvatum in Dance Training: Assessing and Addressing the Structural Deformity in Dancers

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ABSTRACT

Genu recurvatum is a medical condition in which the knee curves backward past the normal range of extension predominantly in the sagittal plane. Hyperextension can be attributed to extra laxity in the body, therefore the surrounding ligaments of the knee allow for the femur and tibia to be placed past a sagittal alignment of 180°, which is the possible knee extension of normal knee alignment. Genu recurvatum, medically viewed as a deformity, is desirable and considered a positive attribute in the dance world, especially classical ballet. Hyperextension also makes the line of the leg appear longer and straighter in ballet positions. Classical ballet requires beauty in form and values length; therefore hyperextension enhances ballet's visual appeal. As aesthetically pleasing and desirable genu recurvatum is in the ballet world, it remains a structural deformity, one that has many repercussions. Genu recurvatum has multiple side effects that impact dance technique, body alignment, muscular development and susception to injury. As a dancer and dance educator with genu recurvatum, it is imperative for me to devise a comprehensive explanation of the condition regarding its effects on dance training and formulate resolutions that empower the educator to address genu recurvatum early in dance education. Early detection and awareness of genu recurvatum in dance students will result in more stable, better aligned and less injury prone dancers.

So much of what makes a dancer with hyperextension a special situation to instruct is that if the instructor does not possess this structural difference, it is difficult to understand how it functions and feels. How does one effectively teach something with which they have no experience?

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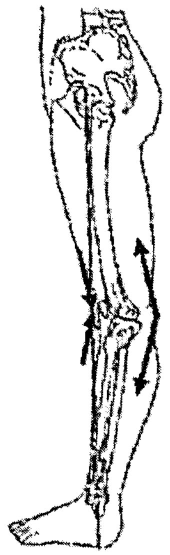
INTRODUCTION

Genu recurvatum is a medical condition in which the knee curves backward past the normal range of extension, predominantly in the sagittal plane as seen in *Figure 1*. Genu recurvatum (L. *genu,* Knee + *recurvus*, bent back) is commonly referred to as 'hyperextension'. Hyperextension can be attributed to extra laxity in the body, therefore the surrounding ligaments of the knee (anterior and posterior cruciate ligaments, medial and lateral collateral ligaments) allow for the femur and tibia to be placed past a sagittal alignment of 180°, which is the typical knee extension of normal knee alignment, genu rectum (Fitt 49).



Genu recurvatum
("Hyperextended knees")

Figure 1

The anterior and posterior cruciate ligaments are arranged to form an 'X'. These crossed ligaments stabilize the tibiofemoral joint while still allowing for a large range of motion. "The knee is provided anterior-posterior (front-to-back) stabilization by the cruciate ligaments" (Arnheim 17). The anterior cruciate ligament (ACL) runs laterally and "Is important for preventing anterior displacement of the tibia relative to the femur" (Clippinger 241). The ACL attaches to the anterior portion of the top of the tibia and runs diagonally up inside the knee joint behind the patella, attaching posteriorly to the bottom of the femur. The main function of the ACL is to prevent hyperextension of the knee.

The posterior cruciate ligament (PCL) "is key in anterior displacement of the femur relative to the tibia" (Clippinger 214). The PCL attaches to the posterior portion of the tibia and runs diagonally up attaching medially to the femur. "The posterior cruciate ligament keeps the shinbone from moving backwards too far. It is stronger than the anterior cruciate ligament and is injured less often" (AAOS). The PCL is responsible for ensuring that the knee joint is not hyper-flexed.

Genu Recurvatum In Dance

Genu recurvatum is prevalent in dancers, and because of this prevalence, the question is often raised as to whether ballet training causes hyperextension. "This is almost certainly not the case. As such, knees give a very pleasing line aesthetically in the working leg. Students with [hyperextension] will tend to be preferentially selected, as evidenced by the large number of dancers with [hyperextended] knees" (Howse 195). Genu recurvatum, medically viewed as a structural deformity, is desirable and considered a positive attribute in the dance world, especially classical ballet.

"Hyperextended legs in which the straightened knee naturally curves behind the thigh and calf muscles are prized in the world of extreme ballet bodies" (Poon 88). "A slight amount of knee hyperextension is considered desirable in some dance aesthetics such as classical ballet" (Clippinger 254). Classical Greek sculptures commonly feature contrapposto or S-Curve positioning of the body. As demonstrated by Alexandros of Antioch's statue *Venus de Milo*, the human eye is attracted to curves in the body. Hyperextension adds an additional curve to the leg and therefore attracts the eye to the knee. Hyperextension also makes the line of the leg appear longer and straighter in ballet positions. Classical ballet requires beauty in form and values length of line; therefore, hyperextension enhances ballet's visual appeal.

As aesthetically pleasing and desirable genu recurvatum is within the ballet world, it remains a structural deformity, one that has many repercussions. "Genu recurvatum is a complex and debilitating structural deformity of the lower limb, and while aesthetically pleasing for dancers, efficient movement patterns must be superimposed to prevent sustaining an acute and/or chronic injury" (Martin 10). Genu recurvatum has multiple side effects that impact dance technique, body alignment, muscular development and susception to injury. "Hyperextended knees often initiate a chain reaction of postural misalignments and are particularly dangerous on landings from jumps or leaps" (Fitt 51).

Personal Connection

I began my dance education at age three, but it was not until age thirteen that I was made aware that I had genu recurvatum. Prior to that, I was under the impression that my knees were no different than any of my other classmates, or humans for that matter. Therefore, I was not addressing my knees any differently in my dance training than my classmates, although I should have. There are photographs of me in ballet class at age six unknowingly sinking into my hyperextension. None of my early dance teachers had hyperextension and they neither assessed nor addressed mine. By the time it was determined that my knees were hyperextended, I had already based the foundation of my dance training on bad habits. These habits were so ingrained in the way that I danced that I am still tackling their correction. Additionally, when instructors advised methods for dealing with my hyperextension later in my dance education, they contradicted other methods that other instructors had previously advised.

Thesis Statement

It is my belief, and current research supports, that had my hyperextension been assessed and addressed early in my dance training, I would be less hyperextended than I am now. Had my hyperextension been assessed and addressed early in my dance training, I would have begun to work with more stability and fewer technical flaws sooner, lending those qualities to overall better dancing. Had my hyperextension been assessed and addressed early in my dance training, I would not continue to have a high likelihood for suffering a future knee injury. Had my hyperextension been assessed and addressed early in my dance training, I would not have improper and unbalanced muscular development. The consequences of not having been trained properly regarding my hyperextension early on in my dance education are vast.

As a dancer and dance educator with genu recurvatum, it is imperative for me to understand the condition, especially regarding its effects on dance training. Early detection and addressing of genu recurvatum in dance students will result in more stable, better aligned and less injury prone dancers. The hope is that the following information will empower the educator to address genu recurvatum early in dance education. It is the duty and responsibility of the dance educator to effectively teach the student in front of them and be sensitive to different body structures present in their students. Genu recurvatum is "a particularly difficult shape of leg to train" (Thomasen 64). It is difficult for a dancer not to hyperextend their legs while dancing. What makes a dancer with hyperextension an even more enigmatic situation to instruct is that if the instructor does not possess this structural difference, it is difficult to understand how the knee functions and feels within ballet technique. Herein lies the problem; how does one effectively teach something with which they have no experience?

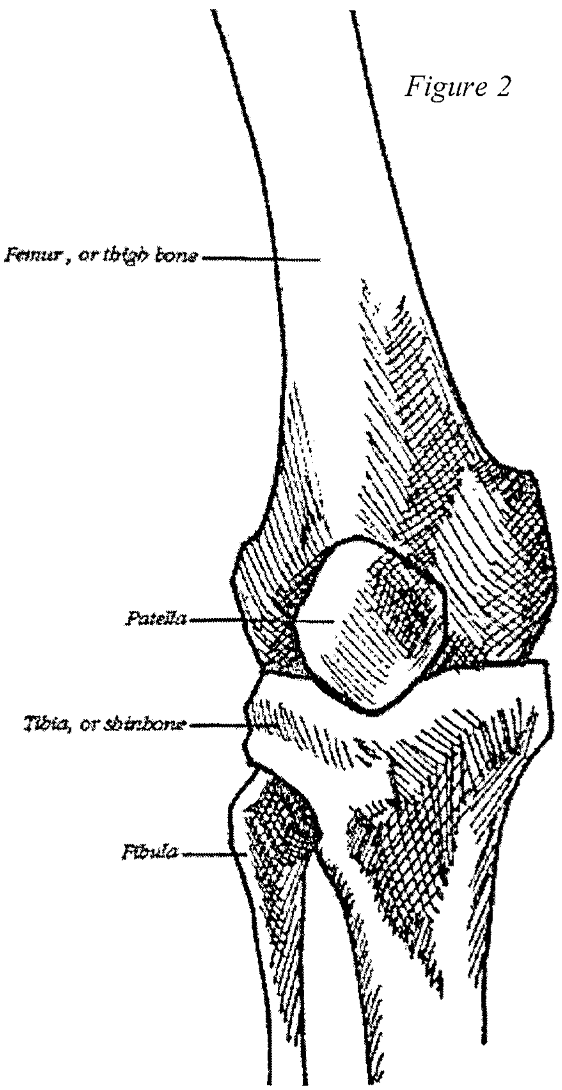
ANATOMY OF THE KNEE

The knee is one of the largest and most complex joints in the body. The knee joint has an extensive network of muscles, ligaments, and tendons that hold it together, stabilize it, and permit it to move. Unlike other joints in the human body, the knee does not gain any stability from its bone structure. It depends entirely on its ligaments, muscles, tendons, and cartilage.

Skeletal

The knee is the "Junction between three bones—the femur, tibia and fibula—surmounted in front by a sesamoid bone, the patella" (Stephens 146). Unlike the elbow joint where the trochlea of the humerus articulates with the trochlear notch of the ulna like a crescent wrench and wraps around the joint posteriorly, in the knee joint the femur balances on top of the tibia, as seen in *Figure 2.* Because of the balancing act between the femur and tibia, the skeletal make up of the knee joint is very week, "only a shallow recess is provided for each femoral condyle (articulating surface of the thigh

Figure 2



bone) to rest on" (Arnheim 16). This means that there is far less stability in the knee joint in comparison to the elbow joint, but additionally there is a greater range of movement in the knee joint than the elbow joint. "When examining the knee joint, one must also consider the patella, a sesamoid bone that forms in the quadriceps extensor tendon. The patella protects the front of the knee and increases the leverage of the quadriceps muscle. Because it articulates only with the femur, a balance of pull on the patella by the quadriceps muscle is essential for smooth knee extension and flexion" (Arnheim 17). A sesamoid bone is a bone that is embedded within a tendon or muscle. Sesamoid bones ossify, turn into bone, later in the body's development, as demonstrated in the patella, which ossifies anywhere between three to five years of age (Scheve).

Menisci

Skeletally, the knee joint is very weak, and therefore depends greatly on the surrounding anatomy to provide stability. "Nature has assisted knee stability by providing two cartilaginous oval pieces that, like the discs between the vertebrae assist in shock absorption and that also provide a slightly deeper socket for the femoral condyles" (Arnheim 16). There are two types of joint cartilage in the knees joint, fibrous and hyaline cartilage. Fibrous cartilage has malleable strength and can resist pressure. Hyaline cartilage covers the surface along which the joints move. The medial and lateral meniscus, both made up of fibrous cartilage, serve to protect the ends of the bones from grinding, as well as effectively deepen the tibial sockets into which the femur attaches. "It adds stability to the joint in that it's shaped like a suction cup to keep the round femur on top of the flat tibia" (Rozien). A secondary job of the menisci is to assist the anterior cruciate ligament and posterior cruciate ligament in providing front and back stability to the knee.

Ligaments

Also contributing to the stability of the knee joint are the surrounding ligaments. "Unlike the hip joint, which derives its strength from its structure, the knee joint has to rely on the many strong ligaments that brace the joint and work collaboratively during movement" (Grieg, 86). Intracapsular ligaments of the knee, notably the anterior cruciate ligament, 'ACL', and posterior cruciate ligament, 'PCL', provide stability while still allowing for a wide range of movement. The cruciate ligaments cross each other like an 'X'. The cruciate ligaments' structure is similar to that of the cords in a toy Jacob's Ladder. Relative to the femur, the ACL keeps the tibia from slipping forward and the PCL keeps the tibia from slipping backward. "Anterior and posterior cruciate ligaments prevent the lower leg from sliding too much forward or backward compared to the thigh" (Peterson 100). "The knee is provided anterior-posterior (front-to-back) stabilization by the cruciate ligaments. By far the greatest strength of the knee joint, however, comes from its musculature" (Arnheim 17).

Outer ligaments of the knee joint, prominently the medial collateral ligament, 'MCL', and lateral collateral ligament, 'LCL', provide medial and lateral stability. The MCL protects the medial side of the knee from being bent open by a stress applied to the lateral side of the knee, a valgus force. The LCL protects the lateral side from an inside, varus, bending force.

Musculature

As stated by Arnheim, the greatest support of the knee joint comes from its musculature. "Muscles such as the quadriceps group, which extends the knee, the hamstring group, which flexes the knee, and the gastrocnemius muscles, which primarily point the toes and assist in bending of the leg, all provide the knee joint with stability if conditioned properly" (Arnheim 17).

The flexors of the knee joint are found in the posterior compartment of the leg. The hamstrings, which flex the knee joint, are the muscles at the back of the thigh that divide into two groups, whose tendons can easily be felt protruding behind the flexed knee. "On the medial side there are the semi-membranosus and semitendinosus and on the lateral side are the biceps femoris. The tendons of sartorius, gracilis, and semitendinosus insert into the upper part of the medial surface of the tibia, forming the pes anserinus" (Ryan 180). Pes anserinus, "goose foot", refers to the conjoined tendons of three muscles that insert onto the front and inside surface of the tibia. Gastrocnemius, plantaris and popliteus are also flexors of the knee joint, but not members of the hamstring group. An additional flexor of the knee, gracillis, is located in the medial compartment of the leg rather than with the rest of the flexors in the posterior compartment.

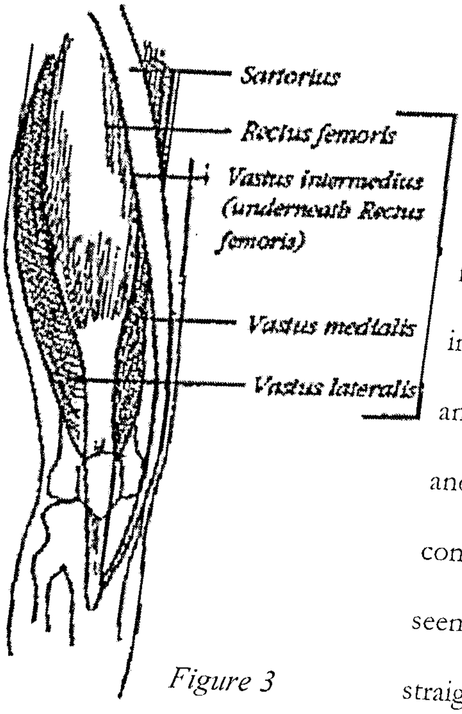


Figure 3

The extensors of the knee joint are predominantly found in the anterior compartment of the leg. The articularis genus, and quadriceps femoris (rectus femoris, vastus lateralis, vastus intermedius, vastus medialis) are located in the anterior compartment of the leg. The sartorius, another extensor is located in the anterior compartment of the leg. The quadriceps group as seen in *Figure 3* is responsible for extension and straightening the knee joint.

Motion

The knee joint itself is classified as a hinge joint. A hinge joint (ginglymus) is a bone joint in which the articular surfaces are molded to each other in such a manner as to permit motion only in one plane. In regards to the knee joint, its hinge nature permits flexion and extension. There is also a slight amount internal and external rotation that occurs within the knee joint. Therefore, "The knee is not a simple hinge joint but has a helical motion" (Stephens 146).

When the knee is extended the lateral and medial collateral ligaments, as well as the anterior part of the anterior cruciate ligament, are taut. During extension, the femoral condyles glide into position. In the flexed position, the collateral ligaments are relaxed while the cruciate ligaments are taut. "Because of the oblique position of the cruciate ligaments at least part of one of them is always tense and these ligaments control the joint as the collateral ligaments are relaxed" (Milon 34).

ANATOMY OF THE HYPEREXTENDED KNEE

Although it possesses all the same anatomy as a typical genu rectum knee, the functional anatomy of a hyperextended knee is distinctive. "A knee which shows a backward deviation past the anatomical vertical reference position is considered hyperextension. Hyperextension of the knee means movement of the knee joint beyond its normal range of extension" (Werner, 9). Hyperextension of the knee can be a result of blunt trauma to the knee as seen commonly in football players, or can be a genetic condition where the laxity of the ligaments and overall hypermobility of the body allows for the joint to over extend, which is predominantly the case in ballet dancers. "Genu recurvatum is more common in females than males, and more common in individuals of any gender with generalized joint laxity ("hypermobility")" (Clippinger 253). How the knee joint moves beyond a normal range of extension in an individual with genu recurvatum depends greatly on the state of the ligaments and muscles that stabilize and power motion of the knee joint. Ligament laxity and muscular imbalances have a great deal to do with the increased sagittal extension evident in a hyperextended knee. Hyperextension "Can be the result of laxity or looseness in the knee ligaments as well as muscular imbalances" (Watkins 116).

Skeletal

Hyperextension perpetuates a chain reaction of postural adjustments that lead to skeletal displacements. Within the knee joint itself the four bones are aligned differently than in a typical, genu rectum knee joint. Because the articulation of the femur and tibia is principally a balancing act, in a hyperextended knee at terminal extension there is even less surface area for the femur to balance upon the tibia. The bones of the hyperextended knee joint also articulate differently when in motion.

> "Normal arthrokinematics of the weight-bearing knee, moving from flexion to extension, consist of the femur rolling anteriorly and gliding posteriorly on the fixed tibia. A relative internal rotation of the femur on the tibia occurs near terminal extension due to the continued anterior rolling of the lateral femoral condyle. With knee hyperextension, the femur does not continue to roll anteriorly but tilts forward, creating anterior compression between the femur and tibia" (Loudon 363).

There are no bones to prevent the hyperextension of the knee. "In the normal knee, bony contact does not limit hyperextension as it does at the elbow. Rather hyperextension is checked by the soft tissue structures" (Loudon 363).

Ligaments

Ligaments provide the flexible link between bones and other bones, but unlike muscles and tendons, once a ligament is stretched, it will stay stretched. In hyperextension, "The knees are pressed backward too far, leaving ligaments at the back permanently stretched" (Werner 5). "Excessive or prolonged stretching of ligaments results in laxity of these structures and loss of the passive tension that is necessary to provide support and protection" (Werner 21). The predominantly overstretched ligament in the case of hyperextension is the ACL. It is indeed the ACL that is loose to facilitate hyperextension. Thus, hyperextension of the knees produces stress on the ligaments, most predominantly the ACL. "A hyperextended position in conjunction with the normal femoral internal rotation results in tension on the ACL and posterior structures of the knee" (Loudon 363).

Muscles

Genu Recurvatum is accompanied by numerous muscular compensations, which develop leg musculature to compensate for the misaligned limb. "Hyperextension is often associated with attempting to maintain stability by "hanging" on ligamental constraints versus using muscular control, knee hyperextension is associated with less activity of the quadriceps than in subjects who stand with knees slightly bent" (Clippinger 270). Hyperextension makes it possible to stand without activation of the quadriceps femoris (rectus femoris, vastus lateralis, vastus intermedius, vastus medialis.)

> "When the knee hyperextends, the axis of the thigh runs obliquely inferiorly and posteriorly, which tends to place the ground reaction force anterior to the knee. In this position, the posterior structures are placed in tension, which helps to stabilize the knee joint, and no quadriceps muscle activity is necessary" (Loudon 363).

This also occurs in individuals following a cerebral vascular accident who lose motor control of the quadriceps and are still able to stand. "Individuals with genu recurvatum may have a functional strength deficit in the quadriceps muscle or gastrocnemius that allows knee hyperextension (Loudon 365). Instead of engaging the quadriceps to stabilize and protect the knees, individuals with hyperextension push their knee joints back for stability.

The quadriceps are also culprit to muscled hyperextension. Although an individual with genu recurvatum can stand, sinking into their hyperextension without the use of the quadriceps, when not weight bearing, the gripping of the quadriceps is common to achieve the same hyperextended line. When the leg is not weight bearing and therefore without the rearrangement of the kinetic chain and gravity, hyperextension does not just occur without muscular contraction. When the leg is not weight bearing passive hyperextension is achievable through manual manipulation, the force of gravity, or muscular contraction. It requires muscular contraction to hyperextend without outside force when in a non-weight bearing situation. "The quadriceps muscles pulls the femur posteriorly in hyperextension; therefore, hyperextension is achieved by the quadriceps muscle" (Werner 26). This can be demonstrated by observing an individual with hyperextension sitting on the ground with their legs out in front of them. The engagement of the quadriceps in this position results in the hyperextension of the knees and the heels popping off the floor. In the same position, with manual manipulation, by lifting the heel off the floor the result is hyperextension of the knee without the involvement of the quadriceps muscles. "Hyperextended knees are sometimes wrongly attributed to excessive strength and use of the quadriceps femoris" (Clippinger 253) However, it should be noted that hyperextension is only sometimes caused by the strength and use of the quadriceps femoris.

The hamstring muscle group is antagonist to the quadriceps muscles. This means that as one muscle is engaged the other is lengthened and stretched. The motions of the muscles are also opposite. Therefore, when the quadriceps are engaged the hamstrings are released and vise versa. The quadriceps are responsible for the extension of the leg and the hamstrings are responsible for the flexion of the leg. "The overstretched knee ligaments and tendons are also usually accompanied by changes in adjacent muscle groups" (Gudmestad). Although the hamstrings are not the muscular power behind hyperextension as their antagonist quadriceps are, the hamstring tendons do reside in the posterior compartment of the knee joint and play a role in the prevention of hyperextension. "There are several large tendons that cross the back of the knee and normally help prevent hyperextension: the hamstring tendons coming down from the back of the thigh and the gastrocnemius tendons coming up from the calf" (Gudmestad). This is to say that because the quadriceps are under-utilized in weight bearing and passive hyperextension that acting as the antagonist muscle group the hamstrings will engage to compensate.

> "It follows that the hamstring and gastrocnemius muscles contract to counteract the quadriceps. In other words, the posterior joint capsule of the knee becomes overstretched by hyperextension and the proprioceptors in this capsule will signal a counterbalancing movement to relax it—a protective reflex. Consequently, the gastrocnemius and hamstrings contract to stabilize the knee" (Werner 26).

Despite its counterbalancing contraction, the hyperextended stance also stretches out the hamstring muscles similarly to how the stance stretches out the posterior ligaments of the knee capsule. When in passive hyperextension, neither the quadriceps muscles nor the hamstring muscles are engaged. Because hyperextension places the knee joint backwards in the sagittal plane, it lengthens the hamstrings more so than if the knee joint fell in line with the plumb line of the body.

The musculature distal to the knee joint also influences hyperextension, most notably the gastrocnemius and the muscle deep to gastrocnemius, soleus, both muscles have a role in restricting the degree of hyperextension of the knee. The gastrocnemius controls knee extension while weight bearing, and is therefore another attributer to hyperextension. "The hyperextension posture of the knee is caused from weakness in the gastrocnemius." (Loudon 365). The soleus has a similar effect. "The soleus originates on the upper tibia and fibula, then runs down the calf to attach to the heel. If it is short and tight, it will pull the upper ends of the tibia and fibula backward, contributing to hyperextension" (Gudmestad).

Ultimately, the musculature dictates the stability of the hyperextended joint. "The degree to which the supporting musculature can be strengthened will determine the amount of control that can eventually be attained" (Grieg 2).

Kinematic Chain

Alignment is the balanced relationship between body parts while standing and moving. "The body's skeleton provides the building blocks, the feet, ankles, knees, hip joints, pelvis, ribcage, neck and head, all balanced one above the other. This balance between parts requires stability among the joints…when one part goes out of alignment, a cantilevering situation is created, requiring the body to tighten many muscles to maintain equilibrium" (Musil 20). In the case of hyperextension, with the knee joint placed out of alignment posteriorly, many adjustments must be made throughout the body to compensate. "It must further be established that misalignment of one joint in the body will most likely cause a chain reaction of other maladjustments to compensate for the loss of stability in that body segment" (Musil 22).

Proper alignment is accomplished with a minimum of excess tension and stress, allowing the superficial musculature to relax while the deep muscles closest to the skeleton are utilized for posture. "The best posture is that in which the body segments are balanced in the position of least strain and maximum support" (Werner 20). Allowing the knees to sink into hyperextension prevents proper alignment from being accessible. As a result of poor alignment of the bones, there is excess stress and tension, which puts joints at risk of injury. "Hyperextended knees often initiate a chain reaction of postural misalignments and are particularly dangerous on landings from jumps or leaps"(Fitt 51). These misalignments and adjustments are observable throughout the entire body and have consequences for more than just the knee joint itself.

> "As the knees curve back, there's a tendency for the pelvis to push forward, the chest to collapse back, and the head to jut forward. These forward-and-back shifts form a system of compensation that can contribute not only to knee problems but also to lower back and neck pain" (Gudmestad).

Lumbar lordosis, or swayback, is a predominant adjustment in the kinematic chain in relation to hyperextension. Lordosis is an exaggerated arching of the back, which is caused by an improper alignment of the pelvis. The tilting of the pelvis dictates posture. "The importance of the function of the pelvis in maintaining the ideal erect posture and its role in good body mechanics cannot be overemphasized"(Werner 5). "Hyperextension of the knee tilts the pelvis forward, resulting in lumbar lordosis" (Werner 20).

Hyperextension also causes the overall placement of weight backwards onto the heels. Having the weight back also contributes to a lordotic posture. "Weight back and [hyperextended] knees will lead to the adoption of a lordotic posture" (Howse 195). As a result of lumbar lordosis, more adjustments are made to spine. "Greater lumbar lordosis will necessitate greater thoracic kyphosis and perhaps cervical lordosis in order to balance the vertebrae" (Werner 21). Kyphosis is an exaggerated rounding of the back. Clearly, the change in alignment caused by hyperextension of the knee results in improper posture throughout the spine and pelvis, therefore stemming poor postural mechanics and an increased likelihood of stress and strain.

Proprioception

Genu recurvatum has a neurological impact as well. Within the structure of the knee joint there is a network of afferent and efferent nerve fibers located within the muscles that send and receive signals to and from the brain. The anatomical adjustments that allow for and are the products of genu recurvatum impact the proprioceptive power of the knee joint. Genu recurvatum results in a functional deficit in the form of diminished proprioception of the knee joint. "Proprioception is the body's ability to get information to the brain in response to a stimulus arising within the body; it also refers to the body's ability to sense the position of its limbs at any moment" (Milon 37). Proprioception has multiple components: a static awareness of joint position, awareness and detection of movement and acceleration within the joint, and a closed loop of neural impulses away from the brain which starts reflex response and regulates muscles (Dhillon). "The proprioceptive sense is believed to be composed of information from sensory neurons located in the inner ear (motion and orientation) and in the stretch receptors located in the muscles and the joint-supporting ligaments" (Milon 37).

The stretched joint capsules, ligaments and tendons that result in hyperextension also house the sensory neurons that contribute to the proprioceptive sense.

> "The stretched joint capsules, ligaments and tendons—are the same tissues that contain the receptors for joint position. Since these same receptors are believed to mediate protective and postural reflexes, it is possible that these responses are also below normal and may increase the chances of acute or chronic injury" (Werner 24).

The ACL being the principally lengthened ligament in hyperextension plays a role in knee joint proprioception. "The ACL has been shown to have significant receptors" (Dhillon 294). It can be concluded that those with hyperextension have poor proprioception when hyperextended. "Hyperextension of the knees could cause a loss of joint proprioception and consequently disruption of postural synergies" (Werner 24). Individuals who stand with their knees hyperextended can have poor proprioception control in the terminal degrees of knee extension. Typically these individuals may perceive the hyperextended position as normal and straight. Deficient proprioception can lead to injury. "Without proper proprioception, the body may not get the right muscles to fire at the right time to protect a joint" (Werner 37).

HYPEREXTENSION AND INJURY

Drawing upon the anatomical deviations that both allow for and stem from the presence of genu recurvatum, it is clear that there are increased opportunities for injury in a hyperextended knee in comparison to a typical, genu rectum knee. "The existence of poor knee mechanics is considered as one of the predisposing factors to injury" (Werner 22). Spinal curve exaggeration, loss of knee joint proprioception, ligamentous laxity, misaligned bones and muscular imbalances all contribute to potential for injury. It should also be regarded that the potential for injury due to hyperextension is not solely present in the knee, but rather throughout the whole body.

Both acute and chronic injuries are possible as a result because of hyperextension. Acute injury is a sudden injury that is usually associated with a traumatic event. Chronic injuries can be also referred to as overuse injuries. Like the name suggests, it is caused by overuse of a particular part of the body. Chronic injuries develop slowly and last a significant amount of time. Acute injuries due to hyperextension tend to deal with the lack of proprioception in the joint. The knee joint when hyperextended takes longer to flex. "When one has a tendency to hyperextend the knees, muscular contraction of the flexors of the knee is needed before the knee can unlock. This makes knee flexion a slower process and may result in injury" (Fitt 51). This can become particularly dangerous when landing jumps. The tendency is for the proprioceptors to brace for landing as the body approaches the ground and place the knee in a flexed position to act as a shock absorber. However, because a hyperextended individual has learned that the hyperextended position of the knee is normal, a properly aligned knee is perceived as bent. Consequently, the landing of a jump can occur on straight legs, despite the neurological signals sent to the knee to flex. This traumatic event can result acute injury.

Chronic injury is also very common in individuals with genu recurvatum. Pain in and around the kneecap, chondromalacia, is one of the most common injuries amongst individuals who are hyperextended. Hyperextension is "associated with an increased incidence of anterior knee pain. In some cases, the resulting laxity of the anterior capsule contributes to misalignment problems, and in others the hyperextended knee causes compression of the infrapatellar fat pad" (Stephens 148). The alignment of the hyperextended knee in relation to the body is a source for both anterior and posterior knee pain. Patella displacement or subluxation can occur, due to poor quadriceps development or general ligamentous laxity. "It is important to recall that the line of gravity falls anterior to the knee joint. Therefore the posterior joint capsule (composed of ligaments) provides the main opposing force to the gravitational pull" (Werner 22).

It should also be considered that the potential for injury due to hyperextension is not exclusively present in the knee, but reasonably throughout the entire body. As discussed before, genu recurvatum usually perpetuates lumbar lordosis, or an exaggerated arching in the lower back. Lumbar lordosis can lead to moderate to severe lower back pain when it is a postural habit. Genu recurvatum also perpetuates cervical lordosis, which can lead to neck pain. Additionally, the unusually high amount of loading placed on the lower leg can result in "shin splints" or even, in more severe cases, tibial stress fractures.

Genu recurvatum presents with general ligamentous laxity. With this in consideration, the ligaments surrounding and stabilizing the knee joint are prone to further stretching.

Ultimately, "The knee is an unforgiving joint; once injured it will continue to give trouble throughout a dancer's career" (Grieg 83).

HYPEREXTENSION IN DANCE

Hyperextended knees are very prevalent in ballet dancers and one study (Trepman et al.,1994) showed that all of the dancers studied exhibited knee hyperextension when standing in turned-out first position, but with significantly greater magnitude in ballet than modern dancers" (Clippinger 270). It is not to say that ballet training causes hyperextension, but rather a Darwinian theory is at play.

> "The question is often raised as to whether ballet training causes [hyperextension]. This is almost certainly not the case. As such knees give a very pleasing line aesthetically in the working leg, students with [hyperextension] will tend to be preferentially selected, as evidences by the large number of dancers with [hyperextended] knees" (Howse,195).

Hyperextension is aesthetically pleasing; therefore it is a trait that is valued in the dance world. Those dancers with hyperextension are then therefore preferentially selected because their knees are more aesthetically pleasing than typical, genu rectum knees. The more attention a dancer gets, the better training they receive and the better they become, leading to future successes. From the beginning of their dance training, a dancer with hyperextension is favorably treated due to the shape of their legs.

In Malcom Gladwell's book Outliers: The Story of Success he sheds light on what makes high-achievers successful. His answer is that there is more focus on what successful people are like, and too little attention is paid to where they are from: that is, their culture, their family, their generation, and the idiosyncratic experiences of their upbringing. Gladwell builds a convincing case for how successful people rise on a tide of advantages, notably Canadian hockey players born in the first three months of the year. In Canada, the eligibility cutoff for age-class hockey programs is January 1st. Canada also takes hockey very seriously, therefore, coaches start streaming the best hockey players into elite programs, where they practice more and play more games and get better coaching, as early as 8 or 9. But who tends to be the "best" player at age eight or nine? The oldest, of course–the kids born nearest the cut-off date, who can be as much as almost a year older than kids born at the other end of the cut-off date. When you are eight years old, ten or 11 extra months of maturity, growth, strength and coordination make a significant difference. The same thing occurs with kindergarten students who are the oldest in their class at the beginning of the school year. There is as great as a 12-month chronological age span between the oldest and youngest kindergartners in a class. A year is a significant difference when a student is five. "And the developmental age span is even greater" (Guignon). This creates a disparity in abilities amongst those students entering kindergarten at different ages. Ultimately, both hockey players' and kindergarten students' idiosyncratic experiences and tides of advantages lead to their successes. The hockey players are stronger, more coordinated and bigger and due to this they get more attention from their coaches. The older kindergarten students have had more time to develop mentally and therefore are stronger students. Due to this, they get more attention and challenges from their teachers. This additional attention pushes the athletes and students further, to continue achieving with mastery.

A similar situation occurs with dance students that are hyperextended. In the case of an individual with genu recurvatum, their 'tide of advantages' is based on the shape of their lower limb. The hockey placers and kindergarten students did nothing to achieve their advantageous trait, and neither do dancers with genu recurvatum. Genu recurvatum is a genetic trait; it cannot be gained. Nevertheless, this advantageous trait garners attention. The more attention a student receives, the more they achieve, and the quicker they advance.

From the beginning of their dance training, a dancer with genu recurvatum is favorably treated due to the shape of their legs. Therefore, a Darwinian theory is at play. As a dancer, having genu recurvatum is a favorable trait, one that can make you an outlier, poised for success.

Aesthetics

Hyperextension of the knees is desirable in the ballet world because it is an aesthetically pleasing trait. Purity of line is held at high regard in ballet due to its visual nature. Hyperextension can create the illusion of a higher, straighter, and longer leg, all attributes that are sought after in ballet technique. "Hyperextension gives the leg a longer look than a single straight line from the hip to the foot might and it is certainly aesthetically delightful to look at" (Peterson 98). "Hyperextension of the knee caused the optical illusion that the entire leg kicked higher" (Werner 25). Classical ballet requires beauty in form and values length; therefore hyperextension enhances ballet's visual appeal.

There are many physical attributes that are prized in the ballet world and the concept of the 'perfect ballet body' edicts everything from head size and neck length to which toe is the longest. Some experts such as Gretchen Ward Warren even include hyperextended legs in their description of the 'perfect ballet body'. "Hyperextended legs in which the straightened knee naturally curves behind the thigh and calf muscles are prized in the world of extreme ballet bodies" (Poon 88).

As mentioned before, classical Roman and Greek sculptures that feature contrapposto or S-Curve positioning of the body such as Alexandros of Antioch's statue *Venus de Milo*, demonstrate that the human eye is attracted to curves in the body. There have been two studies studying the brain's response to different shapes that have results to support that claim. The Zanvyl Krieger Mind/Brain Institute at Johns Hopkins University conducted a study where participants were shown 25 abstract three-dimensional shapes that gradually became more curved, while their brain activity was monitored via fMRI technology. It was concluded that curved shapes produced stronger responses and increased activity in the brain. (Gambino). Similar results occurred for the University of Toronto at Scarborough's study when looking at participant's preferences in architecture. "Brain scans taken while these participants were evaluating the interior designs showed that rounded decor prompted significantly more brain activity, much like what the Johns Hopkins group discovered" (Gambino). It was concluded that our brains find certain shapes more attractive than others. Hyperextension adds an additional curve to the leg and therefore attracts the eye to the knee. This additional curve stimulates increased activity in the brain, and produces a more pleasurable experience for the viewer. Therefore, hyperextension is hardwired in the brain to be more aesthetically pleasing than a straight, genu rectum knee.

Function and Form

Hyperextension, although highly desirable in the dance world, comes with its own unique set of challenges. Adjustments and corrections must be made so that proper ballet technique is established, without increasing the susceptibility for injury. "A dancer must decide for himself or herself which is more important, safety or aesthetic line. It is indeed a choice" (Fitt 249). A dancer cannot chose to have genu recurvatum, the choice is whether the dancer makes adjustments for the sake of safety or does not make adjustments for the sake of aesthetics. A choice where the latter option usually wins. "Aesthetics once again triumphs over the concern for safety and longevity in a dancer's career" (Werner 5). There are many unnatural elements of ballet that push the boundaries of natural body mechanics to achieve aesthetic beauty; hyperextension is no different. "In pursuit of aesthetic form, dancers often force their bodies beyond their limitations" (Werner 5). Hyperextension is clinically considered a debilitating structural deformity, but in the ballet world hyperextension is seen as a gift and in some minds, a prerequisite. Hyperextension is a prime example of "The existence of many contradictions between what science deems mechanically sound or unsound and what dance tradition has labeled aesthetically desirable" (Musil 8).

Form influences function and function also influences form. The presence of hyperextension (form) influences many aspects of technique (function). Ballet technique (function) also influences the severity of hyperextension (form). The presence of genu recurvatum presents many challenges for ballet technique. "Hyperextended knees can cause problems in technique. For example, they prevent a proper first position unless certain adjustments are made" (Ryan, Stephens 181).

Weight Bearing Leg

Hyperextension demands the most adjustments in regards to the supporting (weight bearing) leg. The proper use of the weight bearing leg is essential for the proper execution of steps.

> "While dancing, students are inclined to concentrate their attention on the visible or working leg, the one executing all placements and positions. The functions of the second or invisible leg, the one providing support and mobility, is all too often overlooked. Yet it merits at least as much attention as the working leg. By consciously utilizing the complete length of the

working leg and full participation of the second leg, a step will be presented fully and correctly" (Herstens 40).

As stated before, individuals who are hyperextended are capable of standing without engaging the quadriceps. This tendency permeates to weight bearing positions in ballet as well. The propensity to stand in positions without engaging the quadriceps is problematic when translated into dance, but even more problematic are the postural modifications that accompany this stance. When an individual with genu recurvatum stands without engaging their quadriceps, they completely give way into the full extent of their hyperextension. In this situation the hamstrings are not engaged either. This leaves the supporting leg left without muscular support and relying on the pull of gravity and the misalignment of the knee joint and tautness of the ligaments to stand. The strength of supporting side is at the utmost importance in facilitating proper ballet technique. Without a stable supporting side, utterly all movements become more difficult. Therefore, the supporting side must be sustained with the co-contraction of the surrounding musculature.

Without the use of the quadriceps and the hamstring muscles on the supporting side, the deep rotators (piriformis, gemellus superior, obturator internus, gemellus inferior, quadratus femoris and the obturator externus) responsible for turnout cannot be fully accessed.

In regards to structure, stability and technique, it is disadvantageous to allow the supporting leg to reach terminal hyperextension. Using muscles actively for stability is exponentially safer, more successful and beneficial than using bones and ligaments passively for stability. Additionally, using muscles actively is necessary for executing movements properly.

Gesture Leg

There are no mechanical disadvantages to utilizing the full potential of the hyperextension in the gesture (non-weight bearing) leg. As discussed previously, hyperextension is aesthetically pleasing and makes the leg line look longer, straighter and higher. Hence, the application of the hyperextended line in the gesture leg is aesthetically favorable. Therefore, the recommendation to "meet both biomechanical and aesthetic conditions is to limit the amount of knee hyperextension when the leg is weight bearing and reserve use of a mildly hyperextended knee for the non-weight-bearing gesture leg when aesthetics dictate the "hyperextended line"" (Clippinger 254). This can be most easily applied to barre work, where the body is divided into two sides, and therefore the supporting leg generally remains the supporting leg throughout the combination. In center practice the supporting and gesture legs can alternate quickly, which creates a greater challenge to limit the amount of hyperextension allowed in the weight bearing leg while allowing for hyperextended in the gesture leg. "Hyperextension of the knee is not harmful in the non-weight bearing position, yet is a dangerous stance in a weight bearing leg. However the nature of the dance is such that a leg may be non weight-bearing one moment and, a split second later, weight bearing" (Werner 25).

This presents a unique challenge for those with hyperextension to constantly be aware of which leg is weight bearing and anticipate which leg is about to be weight bearing so that the adjustments can be made. The supporting leg must provide stability to support the body, while the gesture leg provides the motion or articulation through space. The role of the supporting leg can switch instantaneously. There must be a balance of mobility and stability for this to occur efficiently. As already established, individuals with genu recurvatum have a reduced sense of proprioception. Therefore, individuals with genu recurvatum have a weakened ability to sense the position of their knee joint at any moment. It can be thereby concluded that the split of a second adjustments needed to ensure that the weight-bearing leg is not hyperextended and the gesture leg is hyperextended are impeded due to the lack of proprioceptive capabilities.

Jumping

Jumping consists of a preparatory demi plié a spring into a shape in the air and a landing returning to the demi plié, which acts as a shock absorber. "In ballet, as in all forms of dance, motion is fueled by plié. It is essential for the safety of the knee joint that this pivotal movement should be performed *at all times*" (Grieg 90). As established, hyperextension in non-weight bearing situations does not pose a threat to the knee, therefore, while in the air, the legs are free to hyperextend. It is the landing of the jump that is the most dangerous for individuals with hyperextension. "[Hyperextended] legs do not withstand jumps well, as the central line of gravity of the body is not correctly transmitted through the body"(Thomase, Rist 64). It has been concluded that individuals with genu recurvatum have a diminished proprioceptive sense. Typically these individuals may perceive the hyperextended position as normal and straight, correspondingly, individuals may perceive a straight leg as bent. Herein lies the issue. When landing from any type of jump, the execution of a shock absorbing demi plié is crucial. If a hyperextended individual with inherent proprioceptive difficulties prepares to land a jump and thinks they have primed a bent leg for demi plié but in actuality lands on a straight leg the knee is prone to give out and injury is imminent. "Without proper proprioception, the body may not get the right muscles to fire at the right time to protect a joint" (Werner 37). In this case, the correct muscles to fire at the right time in the decent of the jump trajectory are the hamstrings.

Relevé

There is an electromyographic analysis of balance control performed on dancers with and without hyperextension that shows that individuals with hyperextension have a greater difficulty balancing in a relevé (balancing on the balls of the feet) position than those dancers without hyperextension. The presence of hyperextension caused a more difficult balancing situation in this study. It was ultimately concluded that hyperextension necessitates additional muscular activity to maintain balance on relevé. For those with hyperextension the "Tibialis anterior, quadriceps and trunk extensors all increased their response frequencies when compared to [genu rectum subjects]. In fact, they were at their highest response frequency when compare to all other conditions" (Werner 56). A predominant cause for the extra muscular involvement of the trunk extensors in a relevé balance is the tendency for hyperextension to perpetuate other postural misalignments such as lumbar lordosis. "The alignment disruption caused by hyperextension of the knees resulted in more upper body involvement: note the increased response frequencies of the abdominals and the trunk extensors in the [genu recurvatum] condition" (Werner 65).

ASSESSING HYPEREXTENSION

If a dancer's career has been long and relatively injury free, the credit likely due to the dancer's first teacher. Likewise, "In no other training process is poor training so difficult to correct or so painfully evident throughout an entire career" (Musil 2). It is the duty and responsibility of the dance educator to teach the student in front of them and be sensitive to different body structures present in their students. A lack of knowledge about the structure and function of the human body and the application of that knowledge to the training of students can result in a horrifying number of injuries to dancers stemming from poor body mechanics. Additionally, "A teacher must know the kinesiological basis for a prescribed series of exercises and what effects it will produce…the teacher must be able to clearly "see" all the forces action upon a student and how those continued forces will affect that student in the future" (Musil 47).

Ballet is a repetition-based practice. Therefore, whether or not something is practiced incorrectly, it will become permanent. "Years of work in technique classes are devoted to the acquisition of specific control of the body, so that the body can meet the demands placed upon it by [dance]" (Musil 2). The problem arises from the instructor's lack of training in the scientific principles of movement to assess and address these differences in their student's body structure. "In consideration of individual allowances, the teacher must constantly rely on her kinesiological training for help in understanding the mechanical problems that plague the individual dancer" such as genu recurvatum. (Musil 4).

Hyperextension is quite easy to assess in students. Observations made while the young dancer is standing talking to fellow classmates before class can lead to the discovery of genu recurvatum. Simply by the way a student stands can hint at the presence of hyperextension. Not only sinking back in the knees is a postural clue to genu recurvatum, but also lumbar lordosis, thoracic kyphosis and pelvic tipping.

The most definitive way to assess hyperextension is to have the student sit on the ground with their legs extended in front of them in parallel. With relaxed feet (as to not engage the gastrocnemius in plantar flexion nor the tibialis anterior in dorsiflexion) lift the student's heel off the ground slowly and observe where the body accommodates the movement. It is not just that the student can have their heel off the floor without flexion in the hip socket that indicates the presence of genu recurvatum. This could be attributed to the musculature of the gastrocnemius. Rather, if (1) the passive rising of the heel is does not display hip flexion, (2) it can be visually observed that the body accommodates the movement of the heel directly in the knee joint and (3) the back of the knee remains in contact with the floor can it be accurately assessed as genu recurvatum. It is pertinent that the entirety of the back of the knee remains in contact with the floor during this test because it is possible due to muscular development of the gastrocnemius that the heel can be off the floor, without hip flexion, but the back of the knee will not be in contact with the floor and therefore genu recurvatum is not observed. It is also imperative that this test is done with muscular passivity. As discussed before, there is a difference between active and passive hyperextension. This test is not accurate if the quadriceps are engaged.

A clinical assessment of hypermobility in students can be done utilizing the Beighton Hypermobility Scale. The Beighton Hypermobility Scale is a simple system to quantify joint laxity and hypermobility that "is used clinically as a basis of examination and diagnosis" of hypermobility (Smits-Engelsman 1). Through different tests the presence of passive hypermobility is gauged. It uses a simple nine point system where the higher the score the greater the laxity. The threshold for joint laxity in a child ranges from four to six points out of nine. Thus a score above six indicates hypermobility. A score of five out of nine or greater defines hypermobility in adults under the age of 50. (Smits-Engelsman 2). The testing criteria and point system being:

1. Forward flexion of the trunk with knees fully extended so that the palms of the hand rest flat on the floor – one point
2. Hyperextension of the elbows beyond 10 degrees – one point for each elbow
3. Hyperextension of the knees beyond 10 degrees – one point for each knee
4. Passive apposition of the thumbs to the flexor aspect of the forearm – one point for each hand
5. Passive dorsiflexion of the little fingers beyond 90 degrees – one point for each hand (Smits-Engelsman)

It should be noted that the Beighton Hypermobility Scale only quantifies joint laxity. Joint laxity contributes to hyperextension. Also, hyperextension is awarded points in the Beighton Hypermobility Scale. Therefore the Beighton Hypermobility Scale does not indicate hyperextension, but rather hyperextension indicates hypermobility, as is the purpose of the Beighton Hypermobility Scale. It should also be noted that an individual does not have to have a Beighton Hypermobility Scale result above the threshold to be hyperextended. For example, I am hyperextended, but my Beighton score is only four. There is also a possibility that individuals have exceptional Beighton scores of seven, with hypermobility evidenced in every other test but do not present with knee hyperextension. Therefore, the use of the Beighton Hypermobility Scale test should be used to gauge hypermobility in students with the acknowledgement that it does not have a direct correlation with possessing genu recurvatum.

Of course the most accurate clinical assessment of genu recurvatum is measuring the range of motion of the joint with a goniometer. Any measurement beyond 0° is considered hyperextended. A 1997 article in the Journal of Sports Rehabilitation by DeCarlo & Sell found that 96% of the population has some degree of hyperextension with the averages being 5° for males and 6° for females. Although it is improbable to have a goniometer and utilize it when acclimating yourself with your students' body structures, it is the most definitive way to assess genu recurvatum.

ADDRESSING HYPEREXTENSION

It is essential for the student to be immediately informed of their tendency to hyperextend their legs due to the presence of genu recurvatum. "Students must be made aware of the capabilities and limitations of their own bodies. They must be given specific guidelines and instruction, including do's, don'ts and why's concerning the performance of any new technique, no matter how basic" (Musil 48).

Teaching individuals with genu recurvatum is a unique challenge, but even more so if the instructor does not have hyperextended knees. This can be equated to driver's education instructors attempting to teach students how to drive stick shift without ever having driven stick shift themselves. The same rules of the road must be followed and it is still driving a vehicle, yet the key difference being the structure and function. Though both automatic and stick shift transmissions perform the same function, structurally they are very different and therefore require unique actions to garner the same result. Theoretically, it is the same, but the structure demands adjustments to produce the same function. Ballet technique does not change because an individual is hyperextended. Rather, how ballet technique feels with hyperextension is different, and requires unique actions to garner the same results.

There is no circumstance in which an instructor with genu rectum can truly experience the feeling of dancing with hyperextended knees. "A hyperextended position will feel straight: to someone who is used to hyperextending the knees" (Clippinger 270). But a hyperextended position is not physically possible to someone who does not possess genu recurvatum to replicate. Essentially, there is no way for a teacher who does not have this deformity to simulate it as means to fully comprehend how it 'feels'. To overcome this challenge, a substantive quantity of information must be amassed. It is not to say that an instructor without hyperextension cannot effectively train a dancer who has genu recurvatum, but rather that because the instructor cannot experience how the knee feels within ballet technique the instructor must have a solid knowledge of the anatomical principles governing the knee hyperextension. It is very important for both the teacher (hyperextended or not) and the dancer who has genu recurvatum to understand the body mechanics of genu recurvatum. A kinesological approach must be taken to properly train a dancer with hyperextension.

Erroneous Teaching

Poor teaching of individuals with hyperextension runs rampant in dance schools. In some cases, as mine was; the presence of genu recurvatum can be left unaddressed. This almost certainly stems from a lack of understanding of the condition and its kinesthetic and anatomical principles within the realm of ballet technique. Erroneous teaching has consequences. The lack of addressing hyperextension also has consequences. "There is no doubt that bad teachers may aggravate and increase the amount of [hyperextension] by allowing the dancer to push the knee back on the supporting leg" (Howse 195).

In the past, I have been instructed to address my hyperextension in a spectrum of unsound practices. Everything from sinking back into my hyperextension to dancing on bent knees has been suggested. Neither alternative worked for me and I felt equally unstable when utilizing either method. Now with the understanding of the anatomical foundation of genu recurvatum, it is apparent as to why neither method was effective. Although it has clearly been established that genu recurvatum, when in its fully extended splendor is aesthetically pleasing, it is structurally unsound. Consequently, instructing a student to utilize the extent of their hyperextension by 'sinking back' in it causes a myriad of difficulties. Not only does sinking into hyperextension encourage the further lengthening of the ligaments that facilitate hyperextension, but it also causes improper muscular development. "Trouble arises when the dancer "locks" back in to his or her knees and therefore places undue stress on the knee joint and lower leg rather than employing muscle strength for stance" (Harkness Center for Dance Injuries). A major muscular imbalance results in overdeveloped quadriceps and underdeveloped antagonistic hamstrings. This is due to an improper demand and gripping of the quadriceps to maintain stability in the locked back position and the relatively inactive hamstrings. "It is important that younger dancers with naturally hyperextended knees should be taught how to avoid "sitting into" their hyperextension. They should work in first position with the heels together, and should learn to feel the knees "pull up", and not lock back" (Harkness Center for Dance Injuries).

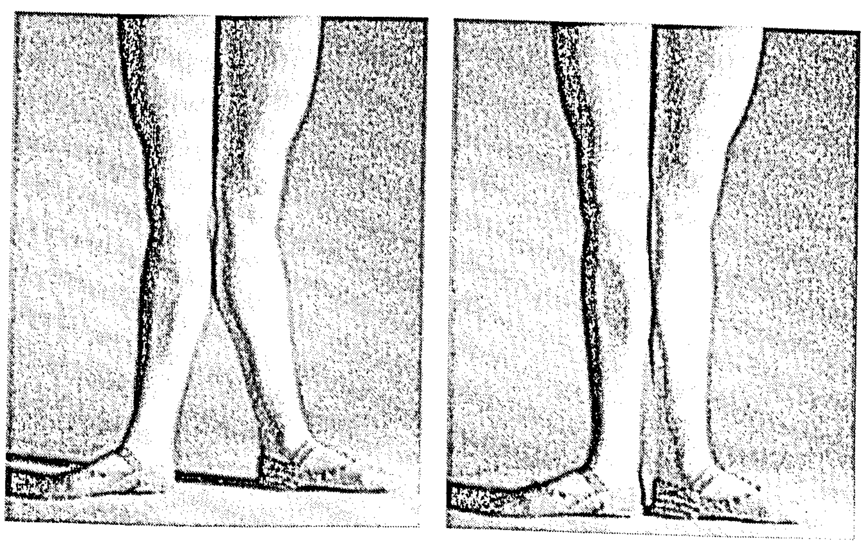


Figure 4

The same dancer in 1st position sitting into hyperextension (left) and without sitting into hyperextension (right)

Dancing on bent knees also causes vulnerability and weakness. Although this approach to genu recurvatum does not exasperate the lengthening of the ligaments as sinking back into hyperextension would, it too causes improper in muscular development. "The hyperextended position will feel straight to someone who is used to hyperextending the knees" (Clippinger 270). But of course despite how straight or 'normal' a hyperextended knee feels to an individual with genu recurvatum, it visually appears hyperextended. Therefore when the knee visually appears straight, with the femur falling directly on top of the tibia without any sagittal deviation, the hyperextended individual will perceive the joint as if it were in a flexed or bent position. Attempting to dance on what is perceived to be bent knees inhibits the quadriceps from engaging and pulling up the patella, a fundamental action in ballet. The patella must be pulled up, not pulling up the patella results in weakness in the vastus medialis oblique muscle, and tightness in vastus lateralis and the iliotibial band which can cause and uneven pull on the patella and result in an even greater propensity for injury.

Not only does dancing on bent knees feel awkward and unstable, it is difficult to define what exactly is 'straight'. The deficient proprioceptive abilities of an individual with genu recurvatum make it increasingly more difficult to accurately and consistently perceive when the knee feels bent but appears straight, rather than when the knee feels bent and actually is bent. This is quite a paradox, one that a young dance student is not capable of deciphering.

Verbal Cues

When navigating the paradox between sinking into hyperextension and dancing on bent knees, instructors commonly rely on words and imagery to guide students into anatomically sound alignment. But verbal cues that are not necessarily specific to those students with hyperextension, which very well may work for individuals with genu rectum, may cause unsound kinematics for individuals with genu recurvatum. Dance teachers erroneously instruct their young students to "pull up the thighs", to which the students respond by pressing back the knees. "Dancers are often instructed to 'pull up the thigh' or 'pull up the hips': since this actually involves locking of the knee, it can present a problem for the hyperextended dancer, who will obviously end up [hyperextended] with tight locking" (Vincent 105). Straight knees are imperative in proper ballet technique; therefore many verbal corrections are given to ensure that students' knees are straight. The issue with this is that for students with genu recurvatum they will respond to that fundamental correction by sinking back in their knees. "Many dance teachers extol maximum extension of the knee to which students respond by contracting the quadriceps muscle to press the knee back to create the line" (Werner 26). These verbal cues that might work well for students with genu rectum can be detrimental to individuals with genu recurvatum. "Hyperextension is, however, presumably, aggravated when young dancers are asked to 'pull up' their thigh muscles for long periods in class. In the course of pulling up, they forcibly extend the knee during periods of growth and development, and older dancers sometimes show a degree of recurvatum that is quite outside the normal range" (Ryan, Stephens 181). Not only do these verbal cues instigate poor technical habits and movement patterns, but also they can increase the degree of hyperextension and increase susceptibility to injury.

Verbal corrections and cues are essential in ballet class, so this is not to say that the instructor must avoid all verbal cues in relation to the knee. There are ways of phrasing these cues that do not result in an immediate contraction of the quadriceps and locking back into hyperextension. "Many instructors have developed different syntax and imagery to appropriately cue dancers with natural hyperextension to work in a more anatomically sound way – encouraging dancers not to 'lock their knees' or 'find the breath behind the knee' are common choices" (Harkness Center for Dance Injuries). The most successful verbal cues in regards to hyperextension deal with more than just "pulling up" one body part. Movement in general has a great deal to do with oppositional energy. Therefore, verbal cues that activate oppositional energies help pull up the patella without sinking back into the knee. I suggest instructing the student to "Pull up just below the back of the knee at the same time that the front of the knee is being pulled up", which encourages a co-contraction of the hamstrings and quadriceps femoris. In hyperextended individuals the hamstring is by default largely inactive. Antagonistic to the hamstrings in a hyperextended individual, the quadriceps femoris is by nature overactive. Therefore, this verbal cue reminds the young dancer to utilize both muscles at the same time in oppositional energy to establish both stability and motion. Oppositional energy incites all muscle groups to work simultaneously by engaging both the muscles used for lengthening, and the opposing muscles used to stabilize or resist that pull.

Avoidance of Particular Stretches

There are a handful of traditional exercises that are done within the context of a ballet class that should be avoided by individuals with genu recurvatum. These exercises can exasperate the extent of the ligamentous laxity within the back of the knee. "Any dancer with [hyperextension] should avoid exercises that overstretch the hamstrings and contribute to joint laxity" (Vincent 105). The most common culprit of encouraging the knee to hyperextend is the traditional ballet barre stretch as seen in *Figure 5*. In this stretch the straight leg is placed on the barre at the ankle and then the dancer executes a series of bends towards and away from the leg. "Stretching with one leg extended and supported by only the ankle on the barre will only worsen the looseness behind the knee" (Vincent 105). Due to the force of

Figure 5

gravity and the lack of support behind the knee, the knee will hyperextend to its fullest extent in this position. If the stretch is executed properly, the leg is at an angle to the floor that makes it easy for gravity to pull the leg into hyperextension. This exercise contributes to the knee joint laxity by overstretching the hamstrings and thereby worsening looseness behind the knee.

Any stretch or exercise that overstretches the hamstrings should be avoided. This is not to say that the hamstrings should never be stretched, as flexibility in the hamstrings is essential for proper movement mechanics within ballet technique. It is to say that any stretch of the hamstrings where the knee is predisposed to hyperextend within the stretch is to be avoided. The issue is when the hamstrings are stretched with the knee at terminal extension. When the hamstrings are stretched while the knee is hyperextended many structures are at risk for over stretching. The soft tissues at risk of being overstretched include the cruciate ligaments deep inside the knee, the medial and lateral collateral ligaments on the inner and outer surfaces of the knee, and the popliteal ligaments, which cross the back of the knee. And of course the large hamstring and gastrocnemius tendons that cross the back of the knee and normally help prevent hyperextension are overstretched.

Hamstring and gastrocnemius stretches should be performed with an awareness of the tendency to hyperextend. Even a simple bend forward touching the toes to stretch the hamstrings can be performed erroneously with hyperextended knees, and with the same effectiveness with a slight release or bend in the knee. When these stretches are performed with hyperextended knees, the stretch originates near the ends of the muscle, rather than the depth of the muscle belly. It is important to be conscious of the position of the knee when performing a hamstring or gastrocnemius stretch.

Kinematic Chain and Alignment

Proper posture and placement "provides the underlying base of stability for every movement" (Vincent 104). Without proper alignment, a dancer's technique is built upon a shaky foundation. Proper training and guidance to promote the discovery of correct placement is necessary or the dancer becomes vulnerable to a battery of injuries and ineffective movement mechanics. As previously established, genu recurvatum perpetuates a string of postural adjustments that take the dancer out of proper alignment. A cantilever position is established to remain upright and the spine is placed in a static undulated position. As the knees curve back into hyperextension, the pelvis will push forward and tip causing lumbar lordosis, the chest will collapse back causing thoracic kyphosis, and the head will jut forward causing cervical lordosis. These sagittal shifts form a system of compensation that can contribute not only to knee problems but also to lower back and neck pain.

To correct the misalignment due to genu recurvatum within ballet technique more than just the alignment of the knee must be tackled, as the entire alignment of the dancer will be compromised. The posture of a dancer begins with head working all the way down through the feet. The head balances on the top of the spine like a seal balancing a ball on its nose. It is essential that the dancer feels the head on top of spine, and that the rest of the body is hanging from plumb line. The chin should to be parallel to the floor with the throat open and the back of neck long. The shoulders and arms are anchored in front of the sternum and clavicle. The sternum is lifted, which is essential for strength and mobility for upper body. The clavicles are held back, in order to achieve full opening of chest. The ribcage is narrowed at the bottom, which provides support for shoulders and arms. The pelvis should neither be tipped backwards nor tucked under. There should be a lift in the front lower abdominal muscles to support the pelvic alignment. The femoral head articulates within the hip socket to create the turnout, which threads all the way down the leg into the feet. Everything distal to the femoral head remains in line so turnout comes entirely from the hip. The foot is in line with the degree of rotation in the hip socket and weight is evenly distributed on the foot through three pressure points in the heel, 1st metatarsal and 5th metatarsal. If one thing is out of line, all other parts of the body adjust and there will be stress upon the body.

In an individual with hyperextension the pelvis will most definitely tip backwards as a reaction to the placement of the knee joint behind the plumb line of the body. This tipping will inhibit proper rotational turnout because there is less room in the hip for the femoral head to articulate with the acetabulum within the hip socket. The tipping of the pelvis will also inhibit proper use of the deep lateral rotator muscles (piriformis, gemellus superior, obturator internus, gemellus inferior, quadratus femoris and the obturator externus) along with gluteus maximus, gluteus medius, gluteus minimus, psoas major, psoas minor and sartorius muscles. The tipping of the pelvis causes a major portion of the body's stabilizing core muscles to remain inactive. The role of these lateral rotators cannot be overstated within their contributions to ballet technique. The function of all six deep rotator muscles is to laterally rotate or turn out the leg, relative to the pelvis. "They achieve this goal by pulling the femur's greater trochanter backwards, that is, toward the back of the pelvis" (International Association for Dance Medicine and Science 3). Therefore, with the presence of genu recurvatum caused pelvic tipping, it is difficult for a dance student to fully access their turnout due to the inhibited rotators caused by the skewed pelvis. The proper placement of the pelvis and its connecting structures is essential for proper ballet technique. Without proper pelvic placement "The working leg cannot achieve a correct turn out in any direction nor provide one with balance in either vertical or horizontal position" (Hertsens 33). Therefore, it is the duty of the dance instructor to correct the position of the pelvis above all else. With proper positioning of the pelvis the subsequent lumbar lordosis will lengthen and straighten the spine into proper alignment. Additionally, because of the proper pelvic placement, the lateral rotators will have the ability to more efficiently engage to increase functional turnout. The use of the lateral rotators will be explored further in relation to genu recurvatum.

Another significant adjustment to the kinetic chain with regards to genu recurvatum is the knee joint itself. The postural plumb line of the body is disrupted when the student is allowed to reach terminal extension of the knee joint. The plumb line is a spatial term that places the body in relationship to the ground. In proper anatomical position the joints of the body would line up in accordance to a straight plumb line to the floor. The plumb line can be traced through all the joints of the body falling on top of each other. The shoulders, hips, knees and ankles should all fall directly in line with each other as seen in on the right in *Figure 5*.

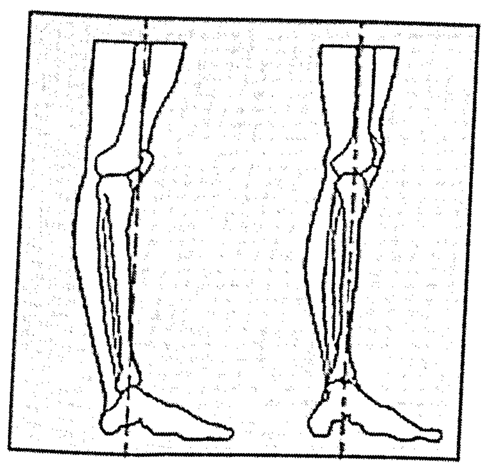


Figure 6

The alignment of an individual is unique, and based upon the body structure of the individual dancer. "Personal placement rests upon the dimensional properties of the individual" (Hertsens 10). The limits of the body ought to be taken into account when formulating technical principles. "Consciously gauging the body's natural dimensions is paramount in the correct technical execution of a step and in obtaining precise, deliberate balance and mobility" (Hertsens 9). Functioning beyond the restriction of one's anatomical dimensions will distort placement of body segments from the plumb line. For an individual with genu recurvatum, their knee joint instinctually falls posteriorly behind the plumb line of the body as seen on the left of *Figure 5.* In this case, the plumb line of the body falls in front of the knee. Not all the joints of the body fall directly in line with each other for an individual with genu recurvatum.

This creates an interesting situation. The plumb line of the body is essential to both balance and motion and individuals with genu recurvatum are missing a segment of their plumb line. Balance and motion are critical elements of ballet dancing. Thereby, individuals with genu recurvatum have a greater challenge of both balance and motion solely in regards to how the joints of their body naturally align themselves. With the knee joint falling behind the alignment of the rest of the joints of the body, the knee does not receive the stabilizing benefits of visualizing the plumb line.

Muscular Development

As discussed before, the presence of hyperextended legs garners improper muscular development. Dancers with hyperextended knees are shown to have overdeveloped quadriceps muscles and underdeveloped hamstrings. Also, due to the associated pelvic tip, the deep internal rotators and gluteal muscles are underdeveloped caused by an inability to fully access those muscles. Additionally, as consequence for the postural adjustments that occur within a dancer with genu recurvatum if left unaddressed, the abdominal wall, most specifically the lower abdominals, are not utilized to their fullest capability and therefore are generally weak. Even the lower leg muscles are underdeveloped due to the presence of hyperextension. The gastrocnemius and soleus muscles are under-utilized and therefore not as developed as in accordance with the technical demands of ballet. Ultimately, the over reliance of one muscle group, the quadriceps, atrophies the rest of the crucial muscles that should be developed.

"The successful management of a greater-than-normal degree of hyperextension depends largely on the strength of the supporting musculature and the intelligence of the dancer"(Grieg 89). To dance with stability and a decreased risk for injury, the hyperextended dancer must consciously recruit the surrounding musculature to support the vulnerable joint. Ultimately, the development of deficient musculature is necessary. Strengthening exercises done beyond ballet class can help actualize this muscular development. "Exercises are given to strengthen all the weak groups which will be in particular the adductors, vastus medialis, hamstrings and gluteals. Abdominals, trunk extensors and latissimus dorsi need to be strengthened" (Howse 196).

Within the ballet class itself these muscles can also be accessed and strengthened. Utilizing the concept of co-contraction of the hamstrings and quadriceps on the supporting leg can alleviate the gripping and overuse of the quadriceps and involve the hamstrings at a greater amount than if the dancer sat back in their knee. Ballet training is based upon repetition and mastery. Consequently, a consistent effort to finding the co-contraction of the quadriceps and hamstrings on the supporting leg can acquire strength in the hamstrings and less activity in the quadriceps. "Since the hamstrings are flexors of the knee, if recruited early enough when the knee is still slightly bent, they can be used to prevent excessive knee extension"(Clippinger 270). Similarly, a consistent effort to have proper pelvic placement will require the involvement of the lower abdominals, therefore over time building their strength. Having corrected the pelvic tip, the rotator and gluteal muscles can be employed for turnout purposes, therefore over time building their strength.

The development of these muscles that were once not in use because of the presence of genu recurvatum can lead to an overall stronger and more stable dancer. This correction of muscular development can also be seen in the shape of the body. The use of proper musculature can transform the shape of the body entirely. The over developed bulk of the quadriceps will diminish over time and giving way to leaner longer quadriceps muscles that fit the ballet aesthetic. The use of these muscles to pull the body into alignment will also change the look of the body. With all body segments appropriately stacked in alignment, the body is free to work efficiently and with a lower degree of stress.

Suggested Method

A single pearl necklace can serve as an analogy for the hyperextended knee with the pearl representing the knee joint and the chain representing the upper and lower leg. If the ends are not held in tension, the pearl will succumb to gravity and fall lower than the ends of the chain. If the ends of the chain are held in tension, the pearl has no choice but to be held in alignment with the chain. In relation to genu recurvatum, if the ends of the leg are not held in opposition the knee will surely fall into terminal hyperextension. But, if the leg is held in opposition, the knee will have no choice but to fall into line. The musculature infrastructure of the leg must be strengthened so that the leg can be held in opposition. With the knee pulled taught in both directions, the knee has no choice but to fall in line. On the proximal end of the limb the lateral rotator muscles provide a source of opposition. With the proper pelvic placement established, the rotators can be fully engaged and used to help pull the knee out of hyperextension. This seems counterintuitive, as the function of the lateral rotators is to laterally rotate the thigh. Engaging the rotators turns out the leg, which flattens the medial aspect of the quadriceps and introduces a spiral sensation to the leg. If the quadriceps are flattened, they cannot be gripped. Hyperextension can be perpetuated by gripped quadriceps. The spiral sensation of the leg encourages the co-contraction of the quadriceps and hamstring muscles, which helps support the knee in proper alignment.

On the distal end of the leg the source of opposition is proper weight placement. The placement of weight on the foot should be evenly shared between the 1st metatarsal, 5th metatarsal and heel. For individuals with genu recurvatum, the tendency is to place the majority of the weight on the heel. Should the majority of the dancer's weight be placed on the heel, the knee has no choice but to hyperextend. If this situation occurs and the knee does not hyperextend to compensate, the dancer will fall backwards. In the case of hypertension, it would be advantageous to redistribute the weight predominantly to the 1st and 5th metatarsals. This is not to say that there should be no weight the heel, as there must be to ensure that the heel does not lose contact with the floor. For a dancer with genu recurvatum their weight will naturally tend to fall into the heel, therefore attention to placing the weight closer to the front of the foot is imperative.

With proper weight distribution on the foot and use of the lateral rotators, the knee is pulled into proper alignment. The knee has no choice but to fall into alignment when held in opposition on both distal and proximal ends; just as the single pearl would not dangle when both ends of the chain are held in tension.

CONCLUSION

Throughout the process of researching and writing this thesis I continued to learn about my own hyperextension, which served as the inspiration for this endeavor. Having implemented the knowledge gained and conclusions made from this thesis I have a comprehensive knowledge of my knees. The attribute that I have always acknowledged as both a challenge to overcome and an aesthetic gift is no longer a mystery for me. Substantive anatomical principles applied to ballet technique have furthered my understanding of my own personal hyperextension. A deeper understanding of how the knee joint functions with hyperextension in situations that I encounter everyday in ballet class have lead to an advance in my technique. Although it is something that is in the forefront of my thought at all times during ballet class (and I anticipate it to be for the remainder of my career), I have become familiar enough with what needs to be done to support and properly align my knee joint that it is becoming instinctive.

Being aware of a diminished sense of proprioception in my knee joint, I can anticipate landings from jumps more accurately to protect myself from landing on a straight knee. Being aware of my postural adjustments caused by my hyperextension has helped me correct the underlying cause for them. Being aware of where I need to place my weight and how to properly pull up my supporting leg has increased my stability both at the barre and in center practice.

I am a better dancer because of this knowledge. This is not solely to my benefit, on the contrary, if these methods were to be integrated in a total teaching approach for training dancers with hyperextension, I contend that the dance discipline would be well on its way to effectively helping students achieve their technical goals while dancing in a safer and more efficient manner.

Ballet technique has continuously been furthered through the application of scientific principles since its codification. All expectations of technique have become more extensive and detailed. Dancers jump higher, turn more, extend their legs higher and dance with more turnout than ever before. The greater the understanding of the body and how it functions the more ballet technique can advance and evolve. This knowledge of genu recurvatum in relation to ballet technique furthers the technique as a whole. Dancers with hyperextension armored with this information can dance with greater stability, strength, and safety than ever before. Dance educators with or without hyperextension armored with this information can instruct students with genu recurvatum to be more stable, better aligned and less injury prone dancers. Utilizing this awareness and application, the thing that made the dancer with genu recurvatum an outlier set up for success in the first place can now become an asset without associated risk.

GLOSSARY

Active hyperextension	hyperextension of the leg with muscular contraction
Acute injury	a sudden injury that is usually associated with a traumatic event such as clashing into another player during sports or a fall from a bike. A traumatic impact can cause your bone to crack, muscles to tear or ligaments to snap.
Antagonist muscle	as one muscle contracts, the other relaxes.
Anterior	front of the human body
Arthrokinematics	pertaining to the movement of bone surfaces within a joint
Atrophy	a wasting or decrease in size or physiologic activity of a part of the body. A skeletal muscle may undergo atrophy as a result of lack of physical exercise.
Barre	the horizontal wooden bar fastened to the walls of the ballet classroom or rehearsal hall which the dancer holds for support. Every ballet class begins with exercises at the bar.
Cantilever	a projecting structure supported on only one end and carrying a load at the other end or along its length.
Center practice	a group of center exercises similar to those at the barre but performed in the center of the room without the support of the bar. These exercises are usually performed with alternate feet and are invaluable for obtaining good balance and control
Cerebral vascular accident	a stroke
Cervical	pertaining to the neck
Chondromalacia	abnormal softening or degeneration of cartilage of the joints, especially of the knee
Chronic injury	injury caused by overuse
Demi plié	half-bend of the knees. All steps of elevation begin and end with demi plié

Distal	anatomically located far from a point of reference, such as an origin or a point of attachment.
Dorsiflexion	flexion or bending toward the extensor aspect of a limb, as of the hand or foot
Extensor	a muscle that extends a joint
Fibrous cartilage	a tough, elastic, fibrous connective tissue that is a major constituent of embryonic and young vertebrate skeletons, is converted largely to bone with maturation, and is found in various parts of the adult body, such as the joints, outer ear, and larynx.
Flexion	the act of bending a joint or limb in the body by the action of
flexors	
Flexor	a muscle that flexes a joint
fMRI	functional magnetic resonance imaging
Genu	the knee
Genu Rectum	Normal knee alignment
Genu Recurvatum	The backward curvature of the knee; hyperextension of the knee
Gesture leg	The leg that is executing a given movement while the weight of the body is on the supporting leg
Ginglymus	a joint that allows movement in but one plane, forward and backward, as does a door hinge.
Hypermobility	unusual flexibility of the joints, allowing them to be bent or moved beyond their normal range of motion
Joint Capsule	a fibrous saclike structure of connective tissue that envelops the end of bones and contains synovial fluid
Kinesiology	the study of motion of the human body
Kinetic	pertaining to or producing motion
Kyphosis	abnormal rearward curvature of the spine, resulting in a protuberant upper back

Lateral — denoting a position farther from the median plane or midline of the body or a structure

Laxity — slackness or displacement in the motion of a joint

Ligament — a band of fibrous tissue connecting bones or cartilages, serving to support and strengthen joints

Line — the outline presented by a dancer while executing steps and poses. A dancer is said to have a good or bad sense of line according to the arrangement of head, body, legs and arms in a pose or movement. A good line is absolutely indispensable to the classical dancer.

Lordosis — an abnormal forward curvature of the spine in the lumbar region

Lumbar — of, near, or situated in the part of the back and sides between the lowest ribs and the pelvis

Medial — pertaining to, situated in, or oriented toward the midline of the body

Menisci — a disk of cartilage that acts as a cushion between the ends of bones in a joint

Motor Control — the systematic transmission of nerve impulses from the motor cortex to motor units, resulting in coordinated contractions of muscles.

Passive Hyperextension — hyperextension of the leg without muscular contraction

Placement — a dancer is said to be well-placed when he or she has learned to hold body, head, arms and legs in their proper alignment to each other, has acquired turn-out of the legs, a well-poised head, level hips and a straight spine in all steps and poses.

Plumb line — a line directed to the center of gravity of the earth

Posterior — directed toward or situated at the back; opposite of anterior

Proprioception — sensation pertaining to stimuli originating from within the body related to spatial position and muscular activity or to the sensory receptors that they activate

Proximal	nearest to a point of reference, as to a center or median line or to the point of attachment or origin
Relevé	raised. A raising of the body on the points or demi-pointes, point or demi-pointe
Sagittal	referring to a vertical plane passing through the body, which divides it into left and right sides.
Sesamoid Bone	Small round bony masses embedded in certain tendons that may be subjected to compression and tension
Subluxation	incomplete or partial dislocation
Superficial	pertaining to or situated near the surface
Supporting Leg	a term used by dancers and teachers for the leg, which supports the body so that the working leg is free to execute a given movement
Tendon	a fibrous cord of connective tissue continuous with the fibers of a muscle and attaching the muscle to bone or cartilage
Thorastic	pertaining to the thorax (chest)
Tibiofemoral	pertaining to the tibia and femur
Turn-Out	the ability of the dancer to turn his or her feet an legs out from the hip joints
Varus Force	bent inward

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