RUNNING HEAD: BIOMECHANICS OF BALLET DANCERS

Biomechanical Differences Between a Grand Plié and a Changement in Female Ballet Dancers

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Abstract

Injuries in the lower extremity in ballet are common due to the high demand that is placed on dancers, with knee and ankle injuries being most prevalent. Research reported in the current literature has been limited to ankle injuries and hip turnout. The purpose of this pilot study is to address the gaps in the literature by comparing peak ground reaction force (GRF) in the landing phase of the *changement*, knee valgus and knee varus angles, knee alignment, and knee torque between two fundamental movements in ballet of a *grand plié* and a *changement.* It is hypothesized that the knee kinetics and kinematics will differ in these movements. One female ballet dancer participated in this pilot study, performing a *grand plié* and *changement* in the biomechanics lab at Point Loma Nazarene University. The data was calculated using a marker-based motion capture system that analyzed the movement of the participant, along with two force plates to calculate the GRF. The results showed that knee kinetics and kinematics do differ between the two movements, with the peak GRF of a *changement* and peak varus of a *grand plié* both being observed to potentially increase knee injury risk overtime due to their high values.

Keywords: ballet, biomechanics, changement, grand plié, kinematics, and kinetics

Review of Literature

Injuries in dance are common, due to the large demand that is placed on the lower extremity during movement. This is possibly due to dancers having only 77% of the weight-predicted normal leg strength in comparison to other types of athletes (Reid, 2012). Injury incidence rates are high, ranging from 67 to 95% in professional ballet dancers with acute or chronic injuries (Kadel, 2006). Dance patients that reported to an emergency department with an injury were 83.3% female, with 76.2% being between the ages of 10 and 18. Out of the injuries that occurred, the most common were an ankle sprain/strain and a knee sprain/strain (Honrado, 2021). Knee injuries make up roughly 14 to 20% of complaints, whereas hip injuries make up only about 10%. In addition to a commonality of ankle, knee, as well as hip injuries, shin and back problems can also occur (Khan et al., 1995).

Foot and Ankle Injuries

It is estimated that 34 to 62% of injuries in dancers come from the foot and ankle, with foot and ankle injuries being more common in females than males. Females have more stress placed on the foot and ankle from wearing pointe shoes, which places the foot in extreme positions. The foot is placed in demi-pointe, and moves en-pointe, which takes the foot through the maximum range of plantarflexion (Kadel, 2006). This extreme use of plantarflexion can produce an excessive force on the posterior ankle that can cause impingement, pain, and ankle instability (Russell et al., 2010). Even though the ankle and foot are strong, they are also sensitive. When injury occurs, this is often a result of incorrect natural movement of the dancers through the joints (Ahonen, 2008)r. The most common foot and ankle injuries to occur are stress fractures, tendonitis, and anterior and posterior impingement (Khan et al., 1995).

Knee Injuries

Knee injuries, as previously stated, make up roughly 14 to 20% of injuries within dance, with over 50% of these injuries being retro patellar. The injuries that are most common at the knee include fat pad syndrome, lateral patellar facet syndrome, medial chondromalacia, subluxing patella, and synovial plica. Sometimes, excessive hyperextension at the knee is seen to cause symptoms in the posterior capsule and poor control in dancers (Reid, 2012). In a recent study, jump landings were analyzed to see the comparisons between a variety of risk factors and injury-causing knee forces. This showed that when the dancers landed while fatigued, greater knee valgus and knee flexion angles were seen, increasing knee anterior sheer force and putting stress on the anterior cruciate ligament (ACL). Increased knee extension was also seen in landing when the dancers were fatigued, putting stress on the medial collateral ligament (MCL) due to a greater knee valgus moment (Holton, 2021).

Hip Turnout

Poor hip turnout, kinematically known as hip external rotation, can result in overuse and non-traumatic injuries in dancers like snapping hip syndrome or stress fractures, which come from incorrect movement compensation due to an insufficient range of motion occurring at the hip (Reid, 2012). A study was done where a group of twenty-nine preprofessional classical ballet dancers from the ages of 15 to 22 had hip external rotation measurements taken in supine and functional turnout with the measurements taken in standing. The injuries shown were associated with reduced functional turnout, rather than hip external rotation, with 93.1% being non-traumatic injuries and 41.4% acute (Negus, Hopper, & Briffa, 2005). In the five fundamental ballet positions, functional turnout uses lower extremity motion primarily occurring through hip external rotation. Because of this, a study was performed to see the relationship between functional turnout and available hip external rotation through using the sum of passive external rotation at both hips and the five ballet fundamental positions. This showed that functional turnout is significantly more than hip external rotation in all five positions, showing that hip external rotation is not a good predictor for functional turnout (Gilbert, Gross, & Klug, 1998).

Fundamental Movements

Different studies analyzed fundamental movements in dance to see how injuries are caused or are affected by these movements. In one study, a *grand plié* was analyzed, where the dancer is in an externally rotated deep squat. This was used to see how ankle sprains can influence postural and muscular control using a group of injured and a group of uninjured dancers. The grand plié was assessed for 15 seconds with a lowering, squatting, and rising phase. The study showed that the group of injured dancers had smaller pelvic motions and center of pressure excursions, greater maximum angles of knee flexion and ankle dorsiflexion, and different temporal activation patterns of the tibialis anterior and medial gastrocnemius than the group of uninjured dancers. It was determined that the group of injured dancers compensated by changing motions in the lower extremity and temporal activation patterns because of their postural challenges (Lin, Su, & Lin, 2014).

Another study occurred to assess hip external rotation by looking at the fundamental movement of vertical jumps in classical ballet dancers. These jumps were assessed in turnout and a neutral hip position using a motion capture system, by recording ground reaction forces and performing an inverse dynamics analysis. The results showed there to be a larger forward trunk lean in the neutral hip position than when in turnout, and a smaller jump in turnout than in neutral. The torque for the hip external rotator was larger in turnout, but the knee extensor and hip abductor torques were smaller. The hip joint movements in the sagittal and frontal plane were relatively similar for both hip external rotation and neutral hip position (Imura & Iiona, 2016).

A fundamental movement of another jump in dance, known as a *sissonne fermée*, was analyzed to assess the neuromuscular and biomechanical characteristics of dancers with and without ankle injury. This jump was performed with reflective markers and electrodes attached to the skin of the participants' lower extremities while ground reaction force, joint kinematics, and muscle activation data were collected. The study showed the injured dancers to have greater peak ankle eversion and smaller posterior foot-to-tibial eversion angles, with greater hamstring activation in the dominant leg and tibialis anterior activation in the non-dominant leg in the pre-landing phase. Additionally, there was greater tibialis anterior activation in the dominant leg and little medial gastrocnemius activation in the non-dominant leg for the injured group. This demonstrated that the injured dancers required more muscle activation to control ankle stability and used a "load-avoidance strategy" in assisting with protection from re-injury (Lee et al., 2012).

A leap in classical ballet was analyzed, known as a *grand jeté,* and was compared to two common jump tests of a countermovement jump (CMJ) and a drop jump (DJ). This study assessed these three movements in classical ballet dancers with different skill levels of professional, semi-professional, and novice. A total of 35 participants were in the study, 10 male and 25 female. In the group of professionals, the highest CMJ vertical displacements and *grand jeté* center of mass (CoM) displacements were seen compared to the semi-professional and novice groups. In the semi-professionals however, the highest DJ vertical displacements were achieved in comparison to the professional and novice groups. In professionals, there was a stronger relationship found between a CMJ and *grand jeté,* and large correlations were found between the *grand jeté*, CMJ, and DJ within all three groups. This demonstrated that the two common jump tests of a CMJ and DJ are accurate in assessing the jumping ability of dancers. The professional dancers were seen to be able to jump higher in ballet-specific jumps, most likely due to their superior set of skills in this area (Blanco et al., 2019).

Gaps in the literature

Honrado (2021) concludes that the most common injuries among female dancers are ankle sprains/strains and knee sprains/strains. Studies conducted addressed ankle injuries' effect on postural and muscular control and biomechanics (Lee et al., 2012; Lin, Su, & Lin, 2014). An additional study addressed hip external rotation's role in lower extremity injuries in comparison to functional turnout (Imura & Iiona, 2016). Hip injuries are rare, compared to ankle and knee injuries. Yet, there is a paucity of studies conducted exclusively on knee injuries in female ballet dancers, with the only analyzation occurring to determine risk factors for jump landings (Holton, 2021).

The proposed study serves to address the gap in injuries in the lower extremity by comparing peak ground reaction force (GRF) in the landing phase of the *changement*, knee valgus and knee varus angles, knee alignment, and knee torque (Nessler, Denney, & Sampley, 2017) between two fundamental ballet movements of a *grand plié* and *changement*. It is hypothesized that the knee kinematics and kinetics will differ between the two ballet movements.

Methods

Participants

One female, adult ballet dancer participated in this study (age: 30; height: 1.65 m; mass: 56.7 kg). This pilot is a larger part of a study that received Institutional Review Board (IRB) approval from Point Loma Nazarene University and written informed consent was obtained from the participant.

Research Design

This study was constructed and refined through a kinesiology committee at Point Loma Nazarene University (PLNU). Quantitative research was performed to explore the fundamental movements that occur at the knee in dancers. This was conducted in the biomechanics lab, through analyzing the movement of the dancer with a marker-based motion capture system. The independent variables in this study were the two fundamental movements of a *grand plié* and *changement* jump. The dependent variables in this study were the motion that occurs at the knee during these two fundamental movements. The specific kinematics and kinetics that were analyzed were the peak ground reaction force (GRF) in the landing phase of the *changement*, knee valgus and knee varus angles, knee alignment, and knee torque. These were chosen as the dependent variables because they have been determined to increase the risk of ACL injury, which is a common knee injury that occurs when high athleticism is required (Nessler, Denney, & Sampley, 2017).

Instrumentation

For the subject, a set of reflective markers that are 9 mm DIA were placed on specific anatomical landmarks of the surface of the skin for the estimation of joint locations and adjoining bone segments. The specific anatomical landmarks for the knee were placed on the medial and lateral condyles, rectus femoris, and tibialis anterior. These were used as a way to define the estimations for joint kinematics and kinetics (Aguinaldo, Buttermore, & Chambers, 2007). The two fundamental movements that were assessed used the motion capture system consisting of 8 visible-red cameras that were used to calculate the 3D global locations of the markers (*Kestrel*, Motion Analysis Corp., Santa Rosa, CA) through a combination with *Cortex* motion capture software at a sampling rate of 240 fps. Two force platforms were used to collect the GRF data (Optima, AMTI, Watertown, MA) through an interface of the motion analysis system occurring at a rate of 1800 Hz.

Data Analysis

Observational analysis was performed on the discrete kinetic and kinematic points extracted from the time-series data. Descriptive statistics were calculated for each kinematic and kinetic variable for both *grand plié* and *changement* movements on the participant.

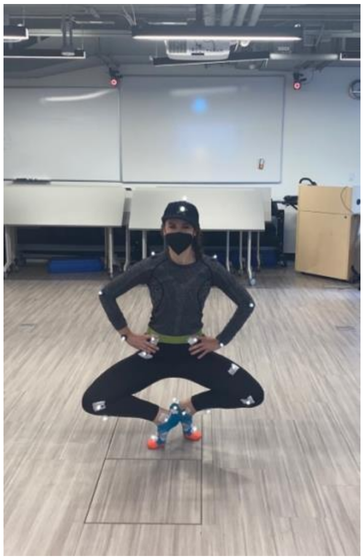

Figure 1: Participant fitted with reflective markers performing a *grand plié*

Results

Summaries of the data from this pilot study are displayed in Table 1, Figure 2, and Figure 3. The results in Figure 2 show the knee joint angle percent motion of extension and flexion and varus and valgus in the two movements of a *grand plié* and *changement,* and the results in Figure

3 show the knee torque percent motion of extension and flexion and varus and valgus in the two movements of a *grand plié* and *changement*. This data was obtained through the motion capture system and *Cortex* motion capture software.

The graph on the left of Figure 2 shows the joint angle in a *grand plié* to be significantly greater in flexion than that of the *changement*, with the *changement* also going into extension during the flight phase of this jump. The graph on the right of Figure 2 shows similarities in the joint angle pattern between a *grand plié* and *changement* with the *grand plié* having a higher varus angle throughout and the *changement* moving from varus to valgus during the flight phase of the jump.

The graph on the left of Figure 3 shows the joint torque in a *grand plié* steadily increasing in flexion throughout the motion. Whereas in a *changement* the joint torque peaks in its greatest flexion in preparation for the jump and quickly moves into extension in the flight phase, proceeding into a lower torque of joint flexion for the landing phase. The graph on the right of this figure shows the *grand plié* to have a greater joint torque throughout varus, whereas in the *changement* the joint torque peaks in varus in the landing phase of the jump.

Table 1 shows the peak ground reaction force (GRF) in newtons (N) and peak varus in nanometers (Nm) in the *changement* and *grand plié*. The peak GRF was greater in the *changement* calculated at 2254 N, and the peak varus angle was greater in the *grand plié* calculated at 88.5 Nm. This is expected because the *changement* is a jump, so the GRF would be greater in a jump than in a *grand plié* due to a larger force being put into the force plates in the landing phase. The varus angle in the *grand plié* had a greater peak due to the maximum external rotation of the hips and knee flexion occurring at the base of this squat position.

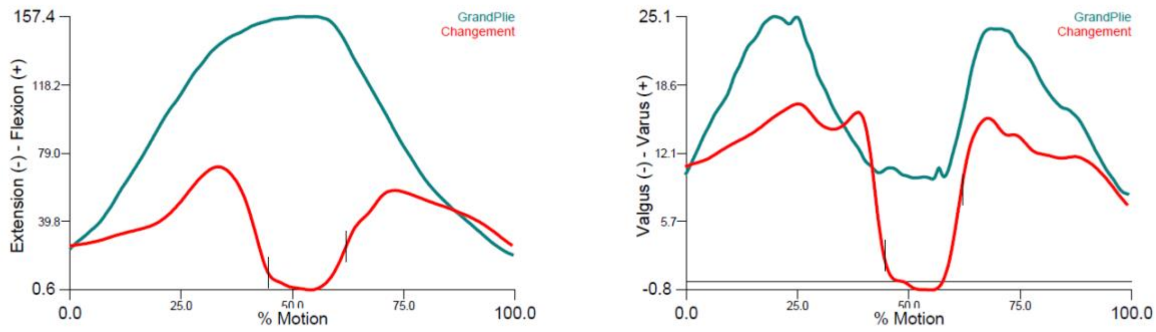

Figure 2: Knee Kinematics of a Grand plié compared to a Changement

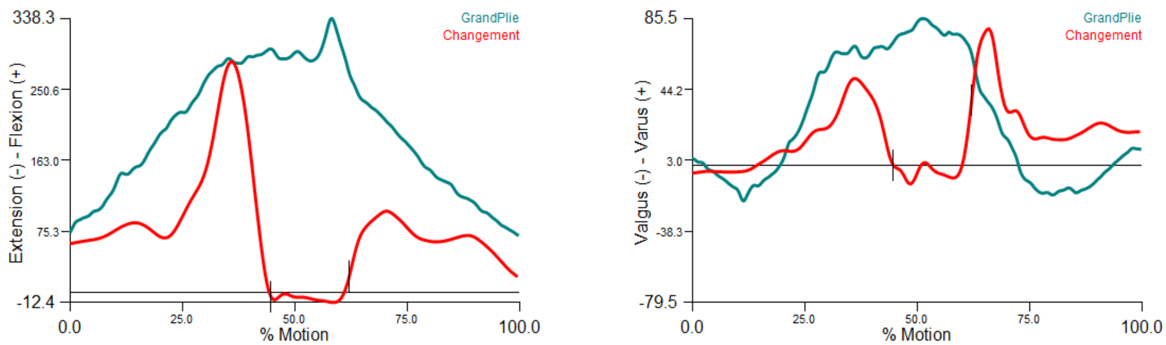

Figure 3: Knee Kinetics of a Grand plié compared to a Changement

Table 1: Significance of Varus and GRF of a Grand plié compared to a Changement

	Peak vGRF (N)	Peak Varus (Nm)
Changement	2254	80
Grand plié	816	85.5

Discussion

The biomechanical comparison of two fundamental movements in ballet of a *grand plié* and *changement* was beneficial to start future research in the study of knee kinetics and kinematics in dancers. This pilot study was correct in its hypothesis that knee kinetics and kinematics would differ between a *grand plié* and *changement*.

The peak GRF in the landing of the *changement* was seen to be greater than at the base of the *grand plié*. This is comparable to the research done previously on jumps, where the *grand jeté* and CMJ had the highest vertical and CoM displacement for professional dancers rather than a DJ (Blanco et al., 2019). This force being greater in the *changement* could potentially increase exposure to knee injury, or other lower extremity injuries overtime. Previous literature showed the most common lower extremities in ballet, acute or chronic, to be an ankle strain/sprain or a knee strain/sprain (Honrado, 2021).

Knee valgus and varus angles were measured, determining that the peak varus torque is greater at the base of a *grand plié*. This varus position repeatedly happening in a *grand plié* and other similar fundamental ballet movements can increase the risk for knee injuries in ballet dancers overtime. Previous research shows this to be caused by poor hip turnout resulting in incorrect movement compensation at the lower extremity (Negus, Hopper, & Briffa, 2005). The peak varus torque was slightly less in a *changement* and occurred in the landing phase of the jump. This is consistent with previous research of vertical jumps, where in a *changement* the torque for the hip external rotator was larger in turnout in than in a neutral hip position and the vertical displacement was highest for a CMJ, in comparison to other jumps (Blanco et al., 2019; Imura & Iiona, 2016). This was seen in the analyzation of dance jump landings, where less of a varus angle was seen and rather a greater valgus angle, putting stress on both the ACL and MCL at the knee, increasing the risk potentially for those injuries (Holton, 2021).

Knee flexion and extension angles were measured, showing that a *grand plié* has a greater joint angle of knee flexion than a *changement*. This is consistent with previous research on a *grand plié* in that there are greater maximum angles of knee flexion that occur for injured dancers than for uninjured dancers in this movement (Lin, Su, & Lin, 2014). This new data collected for this pilot study shows that a *grand plié* position overtime may cause an increase for injury, due to the large angle of knee flexion that is required in this position. In a *changement* knee extension occurs during the flight phase of this jump, with a smaller torque in comparison to the torque occurring in knee flexion for both fundamental movements of a *grand plié* and *changement*. Literature shows this as well with knee extensor torque being smaller with hip external rotation than with a hip neutral position during vertical jumps (Imura & Iiona, 2016).

This pilot study was overall comparable and consistent to previous literature done on lower extremity injuries in ballet dancers, while still collecting new data that can be used for future research on knee kinetics and kinematics and currently filling in some of the literary gaps. In future studies, it would be beneficial to use a larger sample size of at least 10 ballet dancers. This would allow for more data to be collected and better, truer comparisons to be made when analyzing dance movements. Additionally, to have the dancers be at a pre-professional or professional level would allow for the best results due to those levels being the highest intensity, and so prone to the most injury. This age range is from about 15-24 years. Having the participants be both male and female would allow for the most accurate data for all ballet dancers. If conducting data on the knee, having half of the participating dancers have a history of previous knee injury and the other half have no such history would allow for a way to see how previous knee injury effects dance biomechanics or if there is no effect. Other potential ballet movements that could be analyzed for study of the knee besides a *grand plié* or a *changement* are a *passé* and an *échappé*, with a *passé* being used as a stagnant movement like a *grand plié* and the *échappé* as a jump like a *changement.*

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