BIOMECHANICAL STUDY OF JUMPING & LANDING TECHNIQUES: BALLET VS NON-BALLET ATHLETES

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ABSTRACT

Biomechanical Study of Jumping & Landing Techniques: Ballet vs Non-Ballet Athletes

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INTRODUCTION: The prevalence of ACL injuries is increasing in previous years. One of the most common studied kinematic risk factors related to ACL injuries is a resultant weak, leg axis alignment known as the dynamic knee valgus angle presented during a vertical drop jump [8, 14, 15]. Hewett et. al. concluded that a knee valgus angle was a primary predictor of the mechanism that leads to an ACL rupture [8]. By increasing the excessive knee valgus angle during a two-legged DVJ, an athlete is in turn increasing the possibility of a high knee valgus moment, which can increase the anterior tibial translation as well as the load on the ACL several-fold and the chances for an ACL tear [4].

METHODS: In our study, ten collegiate female participants, including ballet and non-ballet athletes performed two-legged DVJs for 6 different flexor and extensor muscles while digital recordings of knee valgus angle were captured at initial contact and push off with simultaneous collection of EMG data.

RESULTS: Results displayed statistical significance for the average valgus angle to estimated GRF ratio for the non-dominant leg at push-off between the ballet and non-ballet athletes (0.8 ± 0.43 vs. 1.8 ± 0.33 degrees/N, p < 0.05). In addition, we also found that the hip extensor activity significantly increased for the non-ballet group and that the lateral thigh CCI noticeably increased for the non-dominant leg for the non-ballet group, which could be indicative of the noticeable difference in the biceps femoris muscle activation for the non-ballet group when comparing sports type. In addition, statistically significant interactions between sports type and leg type for vastus medialis and gluteus maximus were produced. Observed results also indicated that there was an increase in overall variability for the dominant leg of the non-ballet athletes amongst all studied muscles and for the non-dominant leg for the ballet group specifically studying the gluteus maximus muscle activity.

DISCUSSION: Relatively, the non-ballet group could be at a higher risk for increase in femoral adduction, hip adduction, and tibial external rotation, and overall predict a larger knee valgus moment; therefore, the non-ballet group could potentially be at a higher risk for an ACL injury than the ballet group. In addition, there is potential in continued research of neuromuscular differences between ballet and non-ballet athletes to further investigate the vastus medialis and the gluteus maximus muscle activations as well as to investigate the knee valgus moment values.

Keywords: Knee Valgus, Anterior Cruciate Ligament (ACL) Injury, Drop Vertical Jump (DVJ), Neuromuscular
ACKNOWLEDGMENTS

This work was supported by the Hannah-Forbes Project Funding and the CP Connect Interdisciplinary Project-Based Funding, through the Biomedical Engineering Department Weekly Announcements. Special thanks to Dr. Whitt for his guidance and support and Dr. Immanual Williams for assisting with the biomechanics statistical analyses. I am especially appreciative of my research assistants, Tori Barrington, Samantha Campbell, Zach Chalmers, Iridian Vaca, and Gabrielle Cole, for all of their volunteered assistance and continued support. To all my study participants, thank you for all of your dedication and hard work. Opinions, interpretations, conclusions, and recommendations are those of the author.

This is dedicated to my Lolo for always praying for me and to my Nana for always looking down on me.
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1. INTRODUCTION

Research has shown female athletes are more prone to an anterior cruciate ligament (ACL) injury than male athletes due to biomechanical and/or anthromorphical risk factors [1, 6, 9, 20, 21, 24, 25]. There have been multiple studies conducted and meta-analyses evaluated to determine preventative training interventions that could hypothetically decrease the likelihood of non-contact ACL injuries, including the implementation of a neuromuscular training program into athletes’ seasonal routine [1, 6, 9, 20, 21, 24, 25]. The purpose of a neuromuscular injury prevention training program has been studied to improve the unconscious trained muscle firing response to increase the dynamic joint stability so that athletes can maintain proper stability techniques during a dynamic sport activity and, overall, decrease the chances of one’s body moving beyond the normal movement limits [3, 6, 22]. Although compliance towards neuromuscular training programs is proven to be beneficial in reducing the ACL injury incidence in female athletes, an extensive sports-specific training program may not be practical and implementable for female athletes [23]. Thus, screening techniques and tests have been shown to be a more efficient method of predicting biomechanical ACL at-risk female athletes [7, 12, 18]. One of the most common studied kinematic risk factors related to ACL injuries is a resultant weak, leg axis alignment known as the dynamic knee valgus angle presented during a vertical drop jump [8, 14, 15].

In many of these knee valgus jump landing movement studies, the landing risk was evaluated using kinetic, kinematic, and electromyographic parameters, among which a kinematic frontal projection plane angle of the tibiofemoral joint and electromyographic activity can in turn
study the neuromuscular response associated with the knee alignment. Orishimo et. al’s ACL injury investigation was to compare the frontal-plane knee alignment during a drop-landing technique between male and female dancers and team sport athletes [17]. The results showed female team sport athletes landing with a significantly greater peak knee valgus angle than did the other three groups (male team sport athletes and male and female dancers). EMG was used to confirm the activation of knee stabilizing muscles in use during the activity; however, only two muscles were analyzed for the quadricep to hamstring ratio. In addition, female athletes with reduced EMG preactivity of the semitendinosus and elevated EMG preactivity of the vastus lateralis during side cutting has been shown to be at increased risk of future noncontact ACL ruptures [27]. Therefore, performing a more thorough electromyographic analysis doing a similar activity with a similar sample population has the potential to investigate a deeper correlation and potentially determine a biomechanical difference in ACL risk between neuromuscular strength of specific flexors and extensors on either the dominant and non-dominant limbs.

This study examines the kinematic knee valgus alignment and electrical muscle activation using anatomical angle measurements and electromyography of 6 different flexor and extensor muscles between ballet and non-ballet athletes (i.e. soccer and volleyball) during self-initiated two-legged drop vertical jump (DVJ) landings. On the basis of evidence that the neuromuscular system plays a major role in the dynamic knee joint motion, we hypothesized that a more balanced lateral to medial and dominant to non-dominant musculature would decrease dynamic knee valgus during a two-legged DVJ. In addition, we hypothesized that a more musculously balanced athlete (i.e. ballet dancer) compared with a more musculously
imbalance non-ballet athlete would demonstrate this decrease in knee valgus angle upon landing and/or push-off of the DVJ. To our knowledge, the ratios and interaction comparisons using sports type and leg type of leg musculature during a DVJ between a ballet dancer and a non-ballet athlete have not been investigated and may yield additional evidence to elucidate potential factors and treatment interventions related to ACL injuries in female athletes.
Chapter 2

2. METHODS

2.1. Participant Selection and Informed Consent

This study was designed to compare the kinematic knee valgus angles during a DVJ to the electromyographic data of female ballet and non-ballet athletes. Protocols were approved by California State Polytechnic University’s Institutional Review Board and were designed to minimize risk to human participants. Ten collegiate female participants, including ballet and non-ballet athletes, (volleyball, n=2; soccer, n=3; ballet, n=5); aging from 18-22 (19.3±1.4) years old and classifying as non-obese by body mass index (BMI) (21.9±1.8) volunteered for the study. Exclusion criteria included any history of ligamentous injury to the lower extremity that resulted into surgery, current lower extremity injuries, lower extremity injuries within the previous year, neurological or musculoskeletal impairments that would impact balance (i.e. cerebellar disorder, debilitating arthritis), and/or non-competitive level athletes with less than 3 years of experience at the recreational level. (Ten additional subjects were excluded from the analysis due to excessive skin movement, disrupted wireless signals, compromised skin contact, or invalid collection of data.)

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<tr>
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<tr>
<td>Height (cm)</td>
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<tr>
<td>BMI (kg/m^2)</td>
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After recruiting patients via the Biomedical Engineering Department marketing email, an
initial communication between the study manager and the potential volunteer was performed
to discuss the study and participant eligibility. Each interested participant was scheduled for an
appointment slot to visit the Associated Students, Inc. (ASI) Recreation Center at the
Racquetball Courts where the study was explained in more detail and informed written consent
was obtained prior to data collection. After obtaining the informed consent, patients were
screened through a pre-research questionnaire to determine the level of training and ensure
inclusion requirements for the study. Body weight and height of each participant were
recorded.

2.2. Equipment

The sEMG equipment (BioPac; Goleta, CA, USA) allowed for measuring the muscle
activation while the subject performed a two-legged DVJ off of a 30cm Plyosoft Box (Escape
Fitness LTD; West Chester, OH, USA). For each muscle, the BioPac bipolar electrodes
(BioPac EL500, Ag/AgCl electrodes, BioPac Systems, Inc. Goleta, CA, USA) were placed
medially onto each muscle belly of 6 different lower extremity muscles (as shown in
http://seniam.org, Sensor Locations). The bipolar Biopac electrodes provided a differential
sEMG measurement and an interelectrode distance of about 2.1cm (the diameter of electrode).
The BioPac reference electrode was placed on the right kneecap (i.e. electrically neutral tissue)
closest to the BioNomadix EMG2 Transmitter, which was placed superiorly on the inner right
quadricep. The AcqKnowledge 5.0 software (BioPac; Goleta, CA, USA) was used for setup,
data collection, and post-processing. EMG data was collected at a frequency of 2000 Hz and
synched using AcqKnowledge 5.0. Two-dimensional kinematic analysis was performed using
the HudlTechnique application (Agile Sports Technologies, Inc; Lincoln, NE, USA) on an iPhone 8 mobile telephone (Apple, Inc.; Cupertino, CA, USA). Kinetic data analysis was attempted using Heel/Toe Strike Transducers (BioPac TSD111A; Goleta, CA, USA) placed under the heel and toe as the subject performed standard body squats to record the ground reaction forces and investigate balance for future utilization.

2.3. Equipment Protocol

Height, mass, and dominant leg were recorded after consent and the Pre-Questionnaire were obtained. Leg dominance was determined via participant’s interpretation (i.e. kicking a ball). Baseline knee valgus and pronation was estimated via foot tracings and digital capture (specifically the Q angle). Participants were then asked to warm-up with 2 minutes of jumping jacks and/or stretching. Once complete, the subject was then instrumented with a positive and negative sEMG electrode positioned on the medial part of each muscle belly in line with the muscle fibers: vastus lateralis, vastus medialis, rectus femoris, biceps femoris, semitendinosus, and gluteus maximus of each leg (Appendix F, based on http://seniam.org guidelines). The area of skin for electrode placement was cleaned and slightly abraded with an alcohol wipe prior to placement with electrode gel. For the DVJ, participants were allowed to practice and become accustomed to the landing task. Maximum voluntary contractions (MVCs) were performed using a non-elastic material (i.e. a towel) to perform isometric maximum tests for the knee extensors, knee flexors, and stability musculature. For each MVC, the subject was instructed to perform 3 maximum contractions against the non-elastic towel being held opposite of the contraction by one researchers: flexion for the semitendinosus and rectus femoris MVCs; extension for the vastus medialis, vastus lateralis, and biceps femoris MVCs;
90° push for the gluteus maximus. All subjects were given verbal encouragement. The two-legged DVJs were performed as described by Hewett et. al consisting of the subject starting on top of the box (30cm in height) with feet positioned shoulder width apart, being instructed to drop directly off the box, and immediately performing a maximal effort vertical jump [8]. Two successful trials were recorded for each muscle, with the requirement for success being that the EMG signal and a digital recording were obtained. Additionally, once the DVJ trials for each muscle were complete, subjects were instrumented with the Heel/Toe Transducers on the soles of both the left and right foot. Subjects were instructed to perform 5 standard body weight squats at the subjects’ desired pace. The use of experienced athletes in this investigation allowed for a higher performance evaluation; however, the sample size was limited due to athlete availability and equipment capability. Once complete, a Post-Questionnaire was completed to confirm the lack of injuries or discomfort. No participants reported any discomfort while performing this study.

2.4. Analysis

2.4.1. Kinematic Analysis

The digital recording was analyzed at the second DVJ at both initial contact and at push-off. The knee valgus alignment proposed by Paz et. al. was adopted in this study measuring the angle between the line formed from the anterior iliac spine and the middle of the tibiofemoral joint and the line formed between the tibiofemoral joint and the middle of the ankle mortise [19]. The knee valgus angles for both the dominant and non-dominant limbs were recorded along with the quadriceps angle (i.e. Q angle) measured between the femur line and the
extended tibia line. Assuming the dominant leg received the most load, an estimated peak ground reaction force (GRF) was calculated for comparison [16]:

$$mPvGRF = \frac{PvGRF - \bar{b}}{\sqrt{DH}}$$

where $\bar{b}$ is the weighted mean of $b$

$$\text{*PvGRF} = a\sqrt{DH} + b, \ a \sim \frac{\sqrt{2g}}{m_1}, \ b \sim \frac{BW}{2}$$

*DH = 0.3m, $g = 9.8N$

**Figure 1.** Representation of two slightly valgus angles measured from the femur line and the extended tibia line
2.4.2. Electromyography: AcqKnowledge Processing

The muscle activity signal data was processed using root-mean squared values for peak amplitude, integral, and a consistent delta time value (3.008s). The average maximum EMG amplitude normalized against the peak MVC and the standard deviation for each individual muscle was recorded. The maximum EMG amplitudes were then combined by muscle function to relatively analyze medial to lateral [5]:

\[
EMG_{Knee\ Extensors} = \frac{Vastus\ Lateralis + Vastus\ Medialis}{2} \quad \text{Eq. 2a}
\]

\[
EMG_{Knee\ Flexors} = \frac{Biceps\ Femoris + Semitendinosus}{2} \quad \text{Eq. 2b}
\]

\[
EMG_{Hip\ Extensors} = \frac{Gluteus\ Maximus + Biceps\ Femoris + Semitendinosus}{3} \quad \text{Eq. 2c}
\]

The vastus lateralis and vastus medialis were selected to represent knee extensors, with the semitendinosus and biceps femoris chosen to represent knee flexors. These are the muscles that potentially lead to the greatest joint compression. Hip extensors were represented by the...
gluteus maximus, semitendinosus, and the biceps femoris. Co-Contraction indices (CCI) were calculated for maximum EMG amplitudes and multiple muscle groups [5]:

\[
CCI_{Flexors:Extensors} = \frac{\max(VL + VM,BF + ST)}{\max(VL + VM,BF + ST)} \ast (VL + VM,BF + ST)
\]

\[
CCI_{Medial} = \frac{\min(VM,SM)}{\max(VM,SM)} \ast (VM + SM)
\]

\[
CCI_{Lateral} = \frac{\min(VL,BF)}{\max(VL,BF)} \ast (VL + BF)
\]

*Min = maximum EMG amplitudes from the less active muscle group

*Max = EMG values of the more active muscle group

All values were normalized to the subject’s MVC values.

2.4.3. Statistical Analysis

Assuming each jump was independent (i.e. random assignment), two-way analysis of variance with an interaction term was conducted to analyze the effect of sports type (ballet or non-ballet athlete) and leg type (dominant or non-dominant) on the 6 individual muscle’s maximum electromyographic amplitudes (normalized to the subject’s MVC) during a two-legged DVJ. The significance level for all tests was set to 0.05.
Chapter 3

3. RESULTS

Ten collegiate female participants, including ballet and non-ballet athletes, volunteered for the study (2 volleyball, 3 soccer, and 5 ballet; 19.3 ± 1.4 years; 21.9 ± 1.8 BMI). There were no statistical differences found between the ballet and non-ballet athletes for average valgus angles during two-legged DVJs at initial contact (for non-dominant, 188.2 ± 13.4 degrees vs. 196.6 ± 12.3 degrees, p>0.05; and dominant legs, 175.8 ± 17.1 degrees vs. 183.2 ± 4.02 degrees, p>0.05) or at push-off (for non-dominant, 181.4 ± 22.6 vs. 176.2 ± 15.1, p>0.05; and dominant legs, 170.0 ± 20.6 vs. 179.8 ± 7.2, p>0.05). However, by incorporating the estimated peak GRFs into a ratio with the average valgus angles for each subject, statistical significance for the non-dominant leg at push-off between the ballet and non-ballet athletes was found (0.8 ± 0.43 vs. 1.8 ± 0.33 degrees/N, p < 0.05) (Table 2 & Appendix D). In addition, Q-angles were found statistically significant for the non-ballet non-dominant leg compared to the ballet non-dominant leg (9.4 ± 1.1 degrees vs. 11.2 ± 1.9 degrees) (Appendix B-2).
Table 2. Average valgus angle (degrees) to estimated GRF (N) ratio during two-legged DVJs.

Significant differences (p < 0.05) highlighted in bold*. Results are in mean ± SD

<table>
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<th>Valgus Angle/Estimated Force (Degrees/N)</th>
<th>Initial Contact</th>
<th>Push-Off</th>
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<tr>
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<td>Ballet (n=5)</td>
<td>Non-Ballet (n=5) p-value</td>
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<tr>
<td>Non-Dominant</td>
<td>1.5 ± 0.17</td>
<td>0.19</td>
</tr>
<tr>
<td>Dominant</td>
<td>1.65 ± 0.33</td>
<td>1.7 ±</td>
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Two-way analysis of variance with an interaction term comparing between muscles using the sports type and leg type during a two-legged DVJ showed the non-ballet athletes, in general, showed an increase in variability for the dominant leg, especially compared to the non-dominant leg for the same group (shown specifically in each dominant leg muscle box plot, Appendix A-1 - A-6). The rectus femoris was significantly different for the ballet group compared to the non-ballet group (p-value < 0.05), where as the biceps femoris wasn’t significant yet had a noticeable difference between the ballet and non-ballet group. The interaction between sports type and leg type was statistically significant for the vastus medialis and for the gluteus maximus (p-value < 0.05). For both muscle interaction analyses, the sports type functions differently across leg type meaning that the non-ballet dominant leg mean is larger than the ballet dominant leg mean and the ballet non-dominant leg mean is larger than the non-ballet non-dominant leg mean (Appendix A-3 & A-6). This implies that the vastus medialis is working differently across sports type with respect to leg type. In other words, the non-ballet dancers have more muscle activation in their dominant leg compared to ballet
dancers. On the contrary, the ballet dancers had more muscle activation in their non-dominant leg compared to the non-ballet group. In addition, the ballet group also showed an increase in visible variability for the non-dominant leg when studying the gluteus maximus muscle activity compared to the dominant leg.

Using Hall’s et. al. (2010) modified equations, maximum EMG amplitudes for hip extensors, knee extensors, and knee flexors were calculated (shown in Appendix C) [5]. The non-ballet group demonstrated significantly increased hip extensor activity (p-value < 0.05) for the dominant leg during two-legged DVJs compared to the ballet group (Figure 2). No significant differences for the knee extensor or knee flexor activity (p-value > 0.05) were found between the two groups during the DVJs.

Co-contraction indices (CCI) for the knee extensor/flexor, medial thigh, and lateral thigh muscle activity were calculated (shown in Appendix C). Lateral thigh CCI was noticeably increased for the non-ballet group non-dominant leg during the DVJs. There were no significant differences for the medial thigh CCI or the knee extensor/flexor CCI between the ballet and non-ballet group.

Unfortunately, the kinetic data collected using the Toe/Strike Transducers will be used for future equipment and method validation for evaluation.
Figure 3. Co-contraction for knee extensors/flexors, medial thigh muscles, and lateral thigh muscles during two-legged DVJs (*Significance defined as p-value < 0.05)
Figure 4. Maximum knee extensor, knee flexor, and hip extensor EMG magnitudes during two-legged DVJs
4. DISCUSSION

This study compared kinematic knee valgus alignment and electrical muscle activation using anatomical angle measurements and electromyography of 6 different flexor and extensor lower extremity muscles between ballet and non-ballet athletes during a self-initiated two-legged DVJ evaluated at initial landing and push-off. Overall, the goal of this study was to elucidate the potential biomechanical differences and factors in female ballet dancers compared to non-ballet athletes for future study.

Unfortunately, there were no statistical differences found strictly between the ballet and non-ballet athletes for average valgus angles to correlate with the muscle activation patterns. It is important to point out that by incorporating the estimated peak GRFs into a ratio with the average valgus angles for each subject, statistical significance for the non-dominant leg at push-off between the ballet and non-ballet athletes was found (Table 2). Our observed results indicate that there may have been an increase in knee valgus for non-ballet athletes supporting the hypothesis of increased knee valgus angle upon push-off of the DVJ. Dynamic knee valgus (i.e. knee abduction) was defined as the frontal plane motion measuring between the anterior iliac spine to the middle of the tibiofemoral joint down to the middle of the ankle mortise. This elicited relative measurement angles to be compared amongst each subject where $180^\circ$ was defined as neutral. High knee valgus angles can be the result of increasing lateral ligament and lateral muscle activation (i.e. vastus lateralis and biceps femoris) at a higher recruitment rate, in turn causing femoral adduction, hip adduction, and tibial external rotation. Hewett et. al. concluded that knee valgus angles were a primary predictor of the mechanism that leads to
ACL rupture [8]. By increasing the excessive knee valgus angle during a DVJ at push-off, the athlete is in turn relatively increases the risk of the knee abduction moment, which can increase the risk anterior tibial translation as well as the load on the ACL several-fold putting the ACL at a higher stress which can cause an ACL tear [4]. Since increasing the lateral muscle activation (i.e. vastus lateralis and biceps femoris) is associated with the larger knee valgus moment, the noticeable difference in increased biceps femoral muscle activation for the non-ballet group when comparing between sports type would suggest the involvement in this knee instability. In addition, the noticeably increased lateral thigh CCI for the non-ballet non-dominant leg during the DVJs provides evidence to support the inkling of an increased chance for the non-ballet athletes to have a higher knee valgus moment, shown specifically for the non-dominant leg. However, even though the hip extensor significance for the non-ballet group would help support our increased valgus moment hypothesis with the inclusion of gluteus maximus, biceps femoris, and the semitendinosus muscle activations, the overall results of high variability for the non-ballet group prevents using this to support our conclusion. Overall, we can suggest that the non-ballet athletes could potentially be at higher risk of an ACL injury than the ballet group due to the knee valgus angle to GRF ratio, biceps femoris, and lateral thigh CCI statistical support. Unfortunately, our study did not combine the direct GRF kinetic measurement analysis with synchronized kinematic measures; however, clinical professionals are continuously optimizing knee valgus two-dimensional measures as screening tools to create real-time observational screening injury-risk assessments [13, 14, 15]. Our non-ballet valgus angle results did correlate with Orishimo’s et. al. results displaying a greater knee valgus for female team sport athletes compared to the dancers with the limiting factor of our small sample size [17].
In contrast, the rectus femoris muscle activation resulted in a significant difference displaying a noticeable difference between the ballet and non-ballet athletes. The results suggest that there is an increase in quadriceps muscle activation contributing to an imbalance of hamstring:quadriceps activation occurring throughout the two-legged DVJ exercise between ballet and non-ballet athletes that suggests further investigation. Because the ACL is made up of a posterior lateral bundle tibial attachment taut during full extension (i.e. resisting internal rotation at low flexion angles) and an anterior medial bundle taut during full flexion (i.e. resisting anterior tibial translation at high flexion angles), the anterior translation of the tibia and the tibial rotation decrease; however, the ACL is the only ligament preventing the combination of anterior translation and internal/external rotation of the tibia, which at a high load and/or speed could result in an ACL tear [26]. The purpose of the hamstring and quadriceps muscle groups are to control the GRFs in addition to the ACL stabilizing the tibia with the femur from the anterior axis to the medial/lateral axis; therefore, the benefit of an optimal hamstring: quadriceps co-activation pattern is to limit the magnitude of tibial translation anterior to posterior (i.e. tibial shear force) as well as to provide the necessary axial stability in situations of high risk [26]. Our hypothesis predicted the rectus femoris would be greater for the non-ballet athletes to support their unique valgus angle on the non-dominant leg; however, the ballet group elicited a significantly higher rectus femoris muscle activation and a reasonably lower biceps femoris muscle activation. In addition, the variability for the ballet group was noticeably high making it harder to make the assumption that an increased rectus femoris activation in this study would increase the ballet group’s risk of facilitating ACL anterior translation.
In addition, significantly different vastus medialis and gluteus maximus interactions were found. By adjusting for sports type and leg type, we discovered that the ballet athletes had a statistically significant mean vastus medialis and gluteus maximus muscle activation than non-ballet athletes for the non-dominant leg and the dominant leg. This is representative of yet another muscle imbalance amongst both muscles for each group. However, in general, the variability of the non-ballet athletes’ dominant leg results amongst each muscle increases in variability during the DVJ than any of the ballet athlete dominant leg results. We can assume that the variability is related to the different methods of sport-specific training between athletes in the non-ballet group, which confirms that each subject was trained sport-specific. In addition, the ballet group showed an increase in variability for the non-dominant leg when studying the gluteus maximus muscle activity compared to the non-ballet athletes’ non-dominant leg. These results suggest that the musculature of the gluteus maximus may not be trained in the same manner amongst the ballet group. Further investigation into these two neuromuscular activations are recommended for this study.

These observational analyses require additional longitudinal studies to be able to show a repeatable difference between knee valgus angles and muscle activation patterns amongst female ballet and non-ballet athletes during two-legged DVJs. The aims of these studies were to examine the kinematic knee valgus alignment and electrical muscle activation using anatomical angle measurements and electromyography of 6 different flexor and extensor muscles between ballet and non-ballet athletes during a self-initiated two-legged drop vertical jump (DVJ) landings. For example, the theory behind female quadricep dominance adds an
extra superior force and anterior pull from the patella, which could facilitate in an anterior tibial translation, especially over a slightly flexed or extended knee [26].

These studies were limited to 2D kinematic analyses of static images in conjunction with muscle activation due to equipment availability. We can’t specifically state that there was an increase in knee valgus moment without the evaluation of joint loading forces and moment calculations as published data has shown. Therefore, simultaneous 3D kinematic motion analysis and kinetic analysis regarding the contact force at peak knee valgus (i.e. push-off) in conjunction with EMG wasn’t performed, thus further testing is needed to confirm that these findings are valid. Other limitations included not using: large enough sample size, adolescent teenagers going through puberty at higher risk of an ACL injury than a collegiate athlete, ankle stability (i.e. personal shoes), different exercises instead of DVJ (i.e. single-legged activities or cutting maneuvers), speed limitation for the DVJ exercise (i.e. length of “burst” muscle activation), normal mechanical alignment of about 10° valgus, and boundaries for fatigue-resistant. Also, surface EMG electrode placement (secured onto the subjects by multiple assistants) was performed on each pair of muscles for individual analysis instead of all 6 muscles being analyzed from the same DVJ. Lastly, the MVC exercises were performed at each subject’s “maximum strength”; however, multiple subjects performed above their MVCs during the DVJ exercises (standard deviations shown in Appendix E-3).

In conclusion, we can potentially hypothesize that non-ballet athletes have a higher chance of an increased knee valgus moment due to the kinematic knee valgus angle significance after accounting for the GRF and the lateral muscle activation significance. We cannot make any
concrete conclusions stating that a more balanced lateral to medial and dominant to non-dominant musculature of non-ballet vs non-ballet athletes to a decrease in dynamic knee valgus during a two-legged DVJ nor can we state that a more muscularly balanced athlete (i.e. ballet dancer) compared with a more muscularly imbalance non-ballet athlete would demonstrate a decrease in knee valgus angle upon landing and/or push-off of the DVJ. Without the additional tools to provide a complete longitudinal study incorporating kinetics, kinematics, and EMG together, further investigation will need to be conducted. In addition, there is potential in continued research of neuromuscular differences between ballet and non-ballet athletes to further investigate the vastus medialis and gluteus maximus muscle activations as well as to calculate the actual knee valgus moment values. Future study recommendations include using a device similar to the Athos Core and Compression Leggings (Mad Apparel, Inc.; Redwood City, CA, USA), proven to demonstrate the efficacy compared with the BioPac sEMG system, in conjunction with a 3D motion analysis system and ground force plates in order to process inverse dynamics values to evaluate anterior shear forces, external knee abduction moments, and internal/external knee joint rotation shear forces, which are all factors that put the ACL into a high stress injury-related risk [2, 11].
REFERENCES


Appendices

APPENDIX A. Statistical Summary of Muscle EMG Results

Two-Way Analysis of Variation with an Interaction Term

Table 1: Analysis of Variance Model

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<th>Mean Sq</th>
<th>F value</th>
<th>Pr(&gt;F)</th>
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<td>5.146</td>
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<td>13.06</td>
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<td>36</td>
<td>436.9</td>
<td>12.14</td>
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</table>

Figure A-1. Statistical summary of two-way analysis of variation with an interaction term comparing the vastus lateralis normalized EMG amplitudes between sports type and leg type during a double-legged drop vertical jump (DVJ)
Figure A-2. Statistical summary of two-way analysis of variation with an interaction term comparing the vastus medialis normalized EMG amplitudes between sports type and leg type during a double-legged drop vertical jump (DVJ)
Figure A-3. Statistical summary of two-way analysis of variation with an interaction term comparing the semitendinosus normalized EMG amplitudes between sports type and leg type during a double-legged drop vertical jump (DVJ)
Figure A-4. Statistical summary of two-way analysis of variation with an interaction term comparing the rectus femoris normalized EMG amplitudes between sports type and leg type during a double-legged drop vertical jump (DVJ)
**Figure A-5.** Statistical summary of two-way analysis of variation with an interaction term comparing the biceps femoris normalized EMG amplitudes between sports type and leg type during a double-legged drop vertical jump (DVJ)
Figure A-6. Statistical summary of two-way analysis of variation with an interaction term comparing the gluteus maximus normalized EMG amplitudes between sports type and leg type during a double-legged drop vertical jump (DVJ)
APPENDIX B. Statistical Summary of Kinematic Valgus Angle Results

Table B-1. Average valgus angle during two-legged DVJs

<table>
<thead>
<tr>
<th>Valgus Angle (Degrees)</th>
<th>Initial Contact</th>
<th>Push-Off</th>
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<tbody>
<tr>
<td></td>
<td>Ballet (n=5)</td>
<td>Non-Ballet (n=5)</td>
</tr>
<tr>
<td>Non-Dominant</td>
<td>188.2 ± 13.4</td>
<td>196.6 ± 12.3</td>
</tr>
<tr>
<td>Dominant</td>
<td>175.8 ± 17.1</td>
<td>183.2 ± 4.02</td>
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</table>
**Table B-2.** Average Q-angle to during two-legged DVJs

<table>
<thead>
<tr>
<th></th>
<th>Ballet (n=5)</th>
<th>Non-Ballet (n=5)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Dominant</td>
<td>9.4 ± 1.1</td>
<td>11.2 ± 1.9</td>
<td>0.04*</td>
</tr>
<tr>
<td>Dominant</td>
<td>10.0 ± 0.6</td>
<td>10.2 ± 1.3</td>
<td>0.62</td>
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</table>
APPENDIX C. EMG Analysis using Hall’s et. al (2010) Equations

Table C-1. Maximum EMG amplitudes for hip extensors, knee extensors, and knee flexors during two-legged DVJs. Significant differences (p<0.05) highlighted in bold*. Results are in mean ± SD

<table>
<thead>
<tr>
<th>Max EMG Amplitude (x100)</th>
<th>Dominant</th>
<th>Non-Dominant</th>
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<tr>
<td></td>
<td>Ballet (n=5)</td>
<td>Non-Ballet (n=5)</td>
</tr>
<tr>
<td></td>
<td>Ballet (n=5)</td>
<td>Non-Ballet (n=5)</td>
</tr>
<tr>
<td>Hip Extensors</td>
<td>212.6 ± 125.5</td>
<td>412.6 ± 156.7</td>
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<tr>
<td>Knee Extensors</td>
<td>306.3 ± 261.6</td>
<td>462.4 ± 375.5</td>
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<tr>
<td>Knee Flexors</td>
<td>215.0 ± 215.2</td>
<td>354.4 ± 150.3</td>
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</tbody>
</table>
**Table C-2.** Co-contraction for knee extensors/flexors, medial thigh muscles, and lateral thigh muscles during two-legged DVJs. Significant differences (p<0.10) highlighted in bold*. Results are in mean ± SD

<table>
<thead>
<tr>
<th>Co-Contraction Indices</th>
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<th>Non-Dominant</th>
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</thead>
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<tr>
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<td>Ballet (n=5)</td>
<td>Non-Ballet (n=5)</td>
</tr>
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<td>Knee Extensors/Flexors</td>
<td>393.9 ± 370.2</td>
<td>917.3 ± 578.8</td>
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<tr>
<td>(VL+VM,BF+SM)</td>
<td>157.2 ± 117.2</td>
<td>476.2 ± 357.4</td>
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<tr>
<td>Medial Thigh Muscles</td>
<td>248.7 ± 266.8</td>
<td>245.3 ± 152.1</td>
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<tr>
<td>(VL,BF)</td>
<td>117.2 ± 152.1</td>
<td>357.4 ± 195.3</td>
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Figure D-1. Ratio between the contact angle and the estimated peak GRF
APPENDIX E: Maximum Voluntary Contraction Measures

Figure E-1. Knee flexor MVC. Participants sat upright with knee flexed approximately 80-90°. Participant maximally flexed the leg against the resistance. For the gluteus maximus, the subjects’ leg remained at a 90° angle and maximally pressed down at the heel.
**Figure E-2.** Knee extensor MVC. Participants sat upright with knee flexed approximately 90°. Participant maximally extended the leg against resistance from the researcher.
Table E-3. Standard deviations for the max MVC amplitudes for each muscle exercise used for subject EMG normalization

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Dominant/Non-Dominant</th>
<th>Vastus Lateralis</th>
<th>Rectus Femoris</th>
<th>Vastus Medialis</th>
<th>Biceps Femoris</th>
<th>Semitendinosus</th>
<th>Gluteus Maximus</th>
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<tr>
<td>20</td>
<td>N</td>
<td>0.03</td>
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<tr>
<td></td>
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<tr>
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APPENDIX F. Anatomical Positioning of Surface Electrodes

Figure F-1. Representation of the anatomical positions of surface muscles and electrodes orientated in ratio to the muscle fiber directions [10]

The 6 surface electrode sites used in this experiment are highlighted above in yellow, specifically knee valgus muscles. An additional ground reference electrode was placed on the right kneecap (i.e. electrically neutral tissue). The SENIAM guidelines were also used for guidance of electrode placement (http://seniam.org guidelines).
APPENDIX G. Pilot Study

1. PILOT STUDY METHODS

1.1 Participant Selection and Informed Consent

One female pre-professional ballet dancer and one female competitive-level basketball athlete were recruited to participate in a secondary pilot study. Both participants completed a Pre-Questionnaire and signed the California Polytechnic State University of San Luis Obispo’s Kinesiology department’s informed consent form (i.e. Release of Liability, Promise Not to Sue, Assumption of Risk and Agreement to Pay Claims). The two participants were 18 and 21 with BMIs of 21.3 and 22.3 as well as 15 years of active ballet dancer experience and 10 years of competitive basketball athlete experience. Additionally, for inclusion, all participants had no history of ligamentous injury to the lower extremity that resulted into surgery, no current lower extremity injuries, no lower extremity injuries within the previous year, and no neurological or musculoskeletal impairments that would impact balance (e.g. cerebellar disorder, debilitating arthritis).

After recruiting patients via the Biomedical Engineering Department marketing email, an initial communication between the study manager and the potential volunteer was performed to discuss the study and participant eligibility. Each interested participant was scheduled for an appointment slot to visit the Kinesiology Department’s Biomechanics Lab where the study was explained in more detail and informed consent was obtained. After obtaining the informed consent, patients completed the Pre-Questionnaire. Body weight and height of each participant were recorded.
1.2 Equipment

The Kinesiology Department’s Biomechanics Lab utilized four differential surface electrode sensors (Delay’s, Inc., Trigno™ Digital Wireless EMG System, Massachusetts, USA: range = 20m, accelerometer = 150Hz, Gain = 1000V/V) to record muscle activity at 200Hz and synched all data into the EMG system software program (DelSys, Inc.). The two-dimensional (2D) kinematic analysis was performed using a Panasonic HC-V250 camcorder (Panasonic Corporation, USA) collected at 60Hz, 6 reflective markers attached bilaterally using double-faced adhesive tape, and a digitizing software program (Contemplas GmbH, Germany).

1.3 Equipment protocol

Following informed consent, subjects were asked to warm-up with 2 minutes of jumping jacks and/or stretches. Wireless EMG sensors were positioned on the vastus medialis and semitendinosus of each leg. The subject was then instructed to perform 3, 5-second maximum voluntary contractions (MVC) using a non-elastic material (i.e. a towel) attached to the bottom of the foot for the semitendinosus and around the ankle anterior-posterior for the vastus medialis to then perform full extension and flexion MVCs. Once the subject completed the MVC exercises, the subject was instructed to practice at least 2 forward step-ups (FSUP) tasks per leg as described in Paz et. al.’s kinematic analysis study [19]. Once the subject was familiarized with the tasks, they were asked to perform 1 trial of 5 unilateral FSUP tasks each leg, right leg first. The FSUP task involved the subject stepping up onto a 36-cm-high platform starting with the trail leg in approximately 10° hyperextension at the hip and then extending the knee and hip of the leading limb until the trail foot was placed lateral to the lead foot. The
subject then returned the trail foot to the starting position and the process was repeated for all 5 trials for each leg.

Separately, a similar study of 5 unilateral FSUP tasks were performed using the 6 reflective markers attached over the anterior iliac spine, the middle of the tibiofemoral joint, and the middle of the ankle mortise. Two-dimensional kinematic analysis was performed using the frontal plane projection angle of the knee joint. The knee valgus angles amongst the 5 trials on each leg were used for analysis.

1.4 Analysis

1.4.1. Electromyography

Percent MVC was normalized to the subject’s MVC data. All procedures were done by the same researcher. Data was strictly observational.

2. PILOT STUDY RESULTS

Figure 4 shows the %MVC for the vastus medialis and semitendinosus during the 5-FSUP-task trials. The pattern seems consistent between subjects where the right/dominant vastus medialis is the highest %MVC, then the left/non-dominant vastus medialis, left/non-dominant semitendinosus, and the right/dominant semitendinosus. However, no significant differences were noted from this study.
Figure G-1. Represents the %MVC for the semitendinosus and the vastus medialis for both legs during FSUP tasks between a female non-ballet athletes and a female ballet dancer.

Separately, Figure 5 shows the kinematic change in the angle over time throughout the entire 5-FSUP-task trial. The arrows represent the initial push-off, full extension at the top of the 36-cm-high platform, and returning back to the starting point. Subject 1’s left leg seems to increase in valgus angle at initial push-off where as Subject 2’s leg seems to decrease first then increase at push-off. In addition, over the period of the 5 FSUPs, Subject 1’s range of motion seems to decrease towards the last few FSUPs (i.e. minimum angle gets closer to the maximum angle) where as Subject 2’s range of motion overall remains within a relatively consistent interval. Figure 6 shows the maximum and minimum angles between the right and left legs for both subjects as well as the overall range of motion for each subjects’ legs. However, no significant differences were noted from this study.
Figure G-2. **A**, represents Subject 1’s left leg unilateral FSUP tasks (n = 5 FSUPs). **B**, represents Subject 1’s right leg unilateral FSUP tasks. **C**, represents Subject 2’s left unilateral FSUP tasks. **D**, represents Subject 2’s right leg unilateral FSUP tasks. The arrows from left to right are as follows: initial push-off, full extension, back to starting point.
Figure G-3. A, represents the minimum and maximum valgus angle for each leg during the FSUP tasks between both subjects. B, represents the range of motion (ROM) during the FSUP tasks between both subjects (Subject 1 = Ballet; Subject 2 = Basketball)

3. PILOT STUDY DISCUSSION

The pilot study) with one ballet dancer and one basketball athlete studied more closely the difference in hamstring: quadriceps activation by looking at the vastus medialis and semitendinosus during a unilateral FSUP task [19]. We cannot make any concrete conclusions based on our results showing any significant differences. However, the pattern in this study shows that the ballet dancer had an overall higher motor unit recruitment per muscle based on the normalization to their individual MVCs (Figure G-1). The overall pattern between the two subjects included a higher peak muscle activation of the vastus medialis muscle during the FSUP tasks compared to the muscle activation of the semitendinosus. A reduction in the semitendinosus EMG activity has been studied to increase the risk of future noncontact ACL ruptures during a side-cutting maneuvers; because these exercises are different and our sample size was two, we are incapable of making this conclusion [27]. In addition, Figures G-2 and G-3 shows a much larger range of motion from the ballet subject compared to the basketball
player (Appendix G). This could be related to the inability to perform a steady, consistent unilateral step up onto the box, which is also dependent on single leg balance. In addition, we could hypothesize that the imbalance was a result of a slight quadricep dominant movement in response to adding stability to the knee as one brings themselves up onto the box causing a higher EMG activation of the quadricep relative to the hamstring [17]. Other neuromuscular factors contributing to the imbalance could be as described in Hewett et al.’s publication in which they studied how landing biomechanics would be associated with ligament dominance, quadricep dominance, trunk dominance, and leg dominance theory [6].
APPENDIX H. Participant Forms

RESEARCH PARTICIPANT INFORMATION AND CONSENT FORM FOR CLINICAL RESEARCH STUDY

Title: Biomechanical Study of Jumping & Landing Technique: Ballet vs Non-Ballet Athletes

Protocol Vn. 2.0

Sponsor: Dr. Michael Whitt

Study Manager: Ashley Tornio

California Polytechnic State University, San Luis Obispo

Biomedical Engineering

Please read this form carefully. Take time to ask the study manager or study staff as many questions about the study as you would like. Please take your time to make your decision about participating in this study. This Research Participant Information and Consent Form may contain words you do not understand. Please ask the study manager or the study staff to explain any words or procedures that you do not clearly understand.

Purpose of this Form: The purpose of this form is to give you information about a research study in which you have been asked to consider participating. If you sign it, you will be giving your permission to take part in the study. The form describes the reason why the study is being done, what will happen during the study, any benefits and risks to taking part in the study, and any discomforts. You should take part in the study only if you want to do so. You do not have to take part in the study, and if you decide to take part you may withdraw from this study at any time without penalty or loss of benefits to which you are entitled to. Please read this form and ask as many questions as you want to. You should not sign this form if you have any questions that have not been answered to your satisfaction or if you do not understand the answers. You may only participate in this study after you have reviewed and signed this form. After you sign this consent form and agree to participate, you will be identified as a ‘study subject’. You will be given a copy of this signed consent form to keep upon request.

Why is This Study Being Done? The purpose of this project is to better understand the etiology of joint injury in the lower extremity by exploring possible neuromuscular and/or mechanical origins of injury in athletic populations of varying risk. I aim to determine the non-contact biomechanical deficits between college-aged, female ballet dancers and college-aged, female non-ballet athletes by investigating the lower extremity musculature activation during a neuromuscular training intervention to trigger optimal knee valgus. Comparing the biomechanics of ballet dancers and sports athletes may reveal reasons for the ACL discrepancy and provide clues about training effect on neuromuscular coordination.

How Many People will Take Part in The Study? At least 30 subjects (minimum of 10 basketball players and 10 ballet dancers) will be enrolled onto this study performed at the California Polytechnic State University, San Luis Obispo Recreation Center in a Racquetball Court (1st floor).

How Long Will I Be in this Study? You will be on this study for approximately 30 minutes – 1 hour of activity, and potentially a 1-year follow up if you provide an email and follow-up approval. In the first 15 minutes, you will complete the questionnaire and be instrumented with EMG electrodes and markers by having them adhere to your skin. For the next approximately 30-45 minutes, you will perform the jumping and squat movement trials. For the last 5-10 minutes, you will complete the post-questionnaire.

Can I Stop Taking Part in The Study? Yes. You can decide to stop taking part in the study at any time. Tell the study manager if you are thinking about stopping or decide to stop, so that your study manager can help you do this.
and complete your participation in the study, properly and safely. The study manager may take you out of the study at any time if he/she believes it is in your best interest. You may also be taken out of the study if you do not complete the study assessments, or if the whole study is stopped.

**What is Involved in the Study?** Before any study-related assessments and procedures are performed, you will be asked to read and sign this consent form. If you are deemed eligible, you will proceed through study-related assessments and procedures.

**Procedures:** After you agree to participate in this study and sign this document, you will first fill out a pre-questionnaire to determine if you are eligible for participation. Once it is determined that you are eligible, you will be asked to stand on a piece of paper for a foot tracing during squat stance and post-tuck jump. Next, you will instrumented with electromyography (EMG) surface electrodes (skin-mounted) on the medial portion of the vastus lateralis, vastus medialis, and rectus femoris muscles of the quadriceps, biceps femors and semitendinosis representing the lateral and medial hamstring muscles; gastrocnemius lateralis and gastrocnemius medialis representing the lateral and medial calf muscles; and gluteus maximus representing the gluteal muscles. Each subject will also be instrumented with ~16 reflective markers placed bilaterally over the lateral femoral condyle, midshank, anterior superior iliac spine, acromion, lateral humeral epicondyle, and distal radius and on the sacrium and left posterior superior iliac spine per the Helen Hayes system. Next, you will perform the drop-leg vertical jump exercise from a 30-cm platform dropping off the box with both feet leaving at the same time, and then immediately performing a maximum vertical jump, tucking their knees to their chest. Next, you will be instrumented with 4 wireless force transducers with the laboratory setting providing the visual environment. You will perform 2 maximum effort jumps for each muscle being measured, with electrodes on both the dominant and non-dominant legs (i.e. total of 8 muscles equals 8, 1 muscle trials equaling 16 maximum effort jumps). Next, you will perform 2 squats with maximum muscle activation for each muscle being measured, with electrodes on both the dominant and non-dominant legs (i.e. total of 8 muscles equals 8, 1 muscle trials equaling 16 maximum muscle activation squats). Lastly, you will be asked to fill out a simple post-questionnaire regarding current and past physical activities. Your body motion during these tasks will also monitored with two-dimensional video kinematics of the lower extremity and replayed at a later date, where a trained rater will score each individual jump using the landing error scoring system (LESS). You will be asked to fill out an optional simple follow-up questionnaire regarding physical activity and injury approximately one year from today.

**What are the Risks, Side Effects and/or Discomforts of the Study?** This section is intended to give you some idea of the types of problems that could occur if you participate in this study. You might experience some, none, or all of these side effects or problems. Additionally, there is always the possibility that a rare of unanticipated problem not mentioned in this document could occur. The overall risks are minimal in relation to the information that will be gained. Risks associated with exercises and side effects include the following:

- The electrode adhesive may cause minor skin irritation in some subjects
- There is a risk of falling that is slightly elevated from the impact on the feet during jump landing. This risk is not different from that experienced at the training or performance site, or during everyday physical activities. To alleviate this risk, the subject will warm up prior to arrival for data collection. This will include jogging for one minute, and completing one minute of jumping jacks in place. A researcher will be available and positioned ready to assist the subject in case of instability, and frequent rest periods will be allowed.
- There may be other risks that have not yet been identified, and unexpected side effects that have not been previously observed may occur.

**Injury or Illness:** Cal Poly Polytechnic State University of San Luis Obispo will not provide medical treatment or financial compensation if you are injured or become ill as a result of participating in this research project. This does not waive any of your legal rights nor release any claim you might have based on negligence.
Are there Any Benefits to Taking Part in this Study? There are minimal benefits to the individual.

New Information: Any significant information or findings that might change your health or your decision to participate in this study will be communicated to you in a timely manner.

If I take Part in this Study, How will my Privacy Be Protected? All local legal requirements regarding data protection will be enforced. All study findings and documents will be regarded as confidential. The study manager and members of his/her research team must not disclose such information without prior written approval. The anonymity of participating subjects must be maintained to the extent required by law. The names of subjects will not be used when referring to the data in any presentations or publications that result from these experiments. All subjects will be assigned and referred to by a number or letter code. All records, including questionnaires and foot tracings, will be referred to using the number or letter code of the particular subject only. All questionnaires will be stored in a password-protected computers, accessible only by the the study manager and research staff. The questionnaire data will be retained indefinitely except if the participant withdraws from the study before its completion or requests that her questionnaire be destroyed. Data collected under this protocol are specifically for use in the evaluation and analyses conducted in the study. Sample data will not be available for purposes other than as indicated within this protocol. Data will be kept in password-protected computers.

All records, data, and publications from this project will contain only a subject identification number; your name will not appear. Your data from this project will be retained indefinitely by the study manager and may be used for future research purposes, except if you withdraw from the project before its completion. This project’s research records may be inspected by the Cal Poly State University Institutional Review Board or its designees and by Cal Poly State University to ensure that participants’ rights are being protected.

Will There Be Any Cost for Taking Part in this Study? You will not receive compensation for your participation in the project.

If I am Injured While Taking Part in this Study, Will I Receive Compensation for the Injury? No. If a fall does occur, any needed first aid will be administered within the lab. If further medical care is required, you will be responsible for any and all costs. You will not receive compensation.

If you have Questions or Concerns about this Study, Who Should I Contact? You may ask questions about this study before you decide to take part in the study or at any time during the study. Please feel free to ask questions as often as you need. You may reach Dr. Michael Whitt (mdwhitt@calpoly.edu) or Ashley Tornio (atornio@calpoly.edu), at any time at 209-640-2027, if you have any questions, or in the event of an emergency. If you have concerns about the treatment of research participants or any other regulatory concerns, you can contact the Institutional Review Board (IRB), Dr. Michael Black (mblack@calpoly.edu) or Debbie Hart, (dahart@calpoly.edu).
Voluntary Nature of Participation/Withdrawal: Your decision to participate in this research must be completely voluntary. You are free to choose to enter or not enter the study. There will not be any penalty or loss of benefits to you if you decide not to participate. Even after agreeing to take part in this research study, you may withdraw from the study anytime. If you decide to withdraw from the study, there will be no penalty or loss of benefits to you. Before withdrawing from this study, you should notify a person involved with this research that you want to withdraw.

Statement of Consent: I understand that my participation in this study is voluntary. I understand I am responsible for performing the study procedures regarding study participation that are given to me by the study staff. I understand that my participation in the study will be for 30 minutes to 1 hour, and may extend beyond for a 1-year follow-up. I understand that I or my insurance company will be responsible for any costs due to all study-related injuries, if occurs. I have read all the above, asked questions, received answers about things I did not understand, and willingly give my consent to participate in this study. Upon signing this form, I will only receive a copy upon request.

__________________________  __________________________
Participant’s Initials      Date

Contact Information for Follow-up Questionnaire: You will be sent and asked to fill out a follow-up questionnaire regarding physical activity levels and injuries during the period since initial participation. Contact will be made via e-mail. Your contact information will only be used to reach you for follow up and will not be used for any other purpose.

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|                                  |
|                                  |
| Participant’s E-mail             |

|                                  |
|                                  |
|                                  |
| Participant’s Phone Number       |

I HAVE HAD THE OPPORTUNITY TO READ THIS CONSENT FORM, ASK QUESTIONS ABOUT THE RESEARCH PROJECT AND AM PREPARED TO PARTICIPATE IN THIS PROJECT.

__________________________  __________________________
Participant’s Signature      Date

__________________________
Participant’s Name

__________________________  __________________________
Researcher’s Signature       Date

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Post-Activity Questionnaire

Did you experience any pain or discomfort in the following areas?

Yes, □ Knee □ Ankle □ Hips □ Lower Back □ Other ____________

No □

If yes, which number best describes AVERAGE pain or discomfort?

1 2 3 4 5 6 7 8 9 10
No Pain Pain as bad as you can imagine

Which number best describes your experience during the study?

1 2 3 4 5 6 7 8 9 10
Boring Interesting, and would participate again.

Would you wear a pair of leggings during practice or lifting that paired with your phone (via IOS app) that would show you which muscles are and are not firing during specific activity? (i.e. during squats, the app would show if the muscle is physically activating or not; during a rebound or jump, the app would show if your knee was at risk of injury)

□ Yes □ No

□ Other: ________________________________

Any questions or suggestions for the study staff:

________________________________________________________________________________________

Notes: ________________________________________________________________________________