TITLE: Skier’s Edge: Biomechanical Analysis

AUTHOR: Benjamin T. Johannes

DATE SUBMITTED: March 2020

COMMITTEE CHAIR: Michael Whitt, Ph.D., Professor of Biomedical Engineering

COMMITTEE MEMBER: Jared Jones, M.D., Orthopedic Surgeon

COMMITTEE MEMBER: Christiane O’Hara, M.S., Lecturer, Department of Kinesiology and Public Health
ABSTRACT

Skier’s Edge: Biomechanical Analysis

Benjamin T. Johannes

The Skier’s Edge trainer can be used by novice or expert skiers. Testing was performed to analyze if the use of the Skier’s Edge could reduce in shear forces of the valgus moment on the knee joint and anterior cruciate ligament (ACL) due to lesser fatigue of muscle and a higher hamstring to quadricep (H/Q) ratio activity. This leads to a reduction of improper form and an increase in balance. Experiments performed observed the change in muscle activity with the use of the Skier’s Edge over time when compared to other forms of workout (elliptical and or a traditional ski conditioning workout). Comparison of the three workout methods was completed by collecting kinematic, kinetic and electromyographic (EMG) data. Each participant, 9 male skiers (22±3 years old, 70.56±3.44 inches, 206±54 lbs.) and 6 female skiers (22±4 years old, 66.25±3.25 inches, 148±72 lbs.), were separated into even groups between the workout types. Data was collected initially and after a four-week period of exercise for each respective workout group. A relative valgus moment was found with the force and valgus angle data and an H/Q ratio was created using the vastus medialis and semitendinosus EMG data for the respective muscles. The findings of this study show that there were no significant differences between the workout types for either reduction of valgus moment or an increase in H/Q ratio which are indicators of reduced ACL injury. Trends in the data indicate that the elliptical workout may have a positive impact on H/Q when compared to the Skier’s Edge workout. Recommendation for future study includes having participants complete a more intense and longer workout period or to focus on the elliptical and Skier’s Edge workout to test for significant differences to aid in ACL injury reduction.
Keywords: Biceps Femoris, Semitendinosus, Vastus Medialis, Vastus Lateralis, Valgus Moment, Valgus Angle, Kinematic, Kinetic, Electromyograph (EMG), Skier’s Edge, Anterior Cruciate Ligament (ACL), and Medial Collateral Ligament (MCL).
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ACKNOWLEDGMENTS

I would like to acknowledge my advisor Dr. Michael Whitt for the assistance during the project. I would like to acknowledge Dr. Immanuel Williams for his assistance with the statistics used in this report. I would also like to offer my special thanks to my family and friends for their support during the project.
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Chapter 1

INTRODUCTION

1.1 Statement of Problem

Novice and expert skiers use the Skier’s Edge trainer to perform ski conditioning. One pathway in the usage of the Skier’s Edge could be reduced injury benefits. An additional benefit could be a reduction in shear forces of the valgus moment on the knee joint and ACL due to lesser fatigue of muscle and a higher hamstring to quadricep ratio. This leads to a reduction of improper form and an increase in balance. Our hypothesis is that a change in muscle activity will occur with the use of the Skier’s Edge over time when compared to other forms of workout such as the use of an elliptical and or a traditional ski conditioning workout.

1.2 Purpose of Study

The purpose of this study is to take initial data collection of kinematic, kinetic, and EMG data and to complete a four-week ski conditioning workout. The ski conditioning workouts were divided into three groups (Ride Skier’s Edge, Elliptical, Traditional Ski Conditioning workout), and to collect final data of kinematic, kinetic, and EMG data. Data was analyzed using Excel ToolPak Add-in and JMP 14 to compare ratios of EMG data (RMS), valgus angles, and force distribution and balance data. These comparisons will be made between the three workout groups as well as the before and after of each individual to see if the workouts made a difference in muscle activity and rate of cycles for riding laterally, if there was a potential decrease a relative measure of valgus moment, and difference in force distribution and balance while on the Skier’s Edge.
1.3 Skier’s Edge

The Skier’s Edge is a workout and conditioning device designed to be used to train leg and core muscles in a more unique method as compared to traditional workout methods. The Skier’s Edge works by having a person stand and move on pivoting foot platforms that are mounted to a base with rollers that allow the whole base to ride on a set of arched rails as shown in figure 1.

![Image of T7 Skier’s Edge](www.skiersedge.co.uk/products/)

**Figure 1.** The Skier’s Edge T7 ski conditioning machine. [Image of T7 Skier’s Edge]. Retrieved from www.skiersedge.co.uk/products/.

The moving base is attached to a thick rubber belt that adds resistance to the movement of the base and adds a bounce-back movement. The person trains on the Skier’s Edge by standing on the pivoting platforms and moving the legs side-to-side to mimic the movements that generally occur while someone is performing downhill alpine skiing. The pivoting platforms are for both feet and allow the user to have the legs extend out at an angle while the upper body stays upright and straightforward. The rubber belt has a tensioning device that allows the resistance to be increased or decreased based on skill level and weight of the user. In the case of this study since novice skiers were involved an added component needed was a balance bar
that was attached to the bottom of the device to allow users to have a stable handhold while the device was in operation. The Skier’s Edge is currently being used by professional ski teams such as the U.S. Olympic ski team and other ski teams internationally. It is also being used by different sports teams in American football, hockey, soccer, and golf (G. Miller, Phone Interview, May 18, 2019). It is important to understand if the Skier’s Edge helps with training the muscles for athletes who participate in sports that require and cause a great deal of forces and stress in a lateral movement. The reason being that these movements apply moments and forces on the knee joint in a way that can potentially damage it if the knee joint is not fully supported.

BACKGROUND

2.1 Downhill Alpine Ski Racing Injury

Downhill Alpine Ski racing injury is a topic that lacks studies on it for the seriousness of the issue and how it can affect an athlete’s career. Among the Olympic winter sports, alpine ski racing is known to be a sport that has an above average risk of injury. Only recently has there been an increase in surveillance on the issue done by the International Ski Federation (FIS) by creating the Injury Surveillance System (ISS) that records injuries from participation in the World Cup based on retrospective interviews (Spörri, Kröll, Gilgien, & Müller, 2017). With these interviews it has helped to determine the type and severity of injury for skiers and what the skier was doing when the injury occurred. Results from these had shown the most frequently injured body part was the knee at a 35.6% injury rate and the lower leg at an 11.5% injury rate (Florenes et al., 2009). It is also known that based on the interviews it has been shown that nearly all injuries, approximately 80%, occur while the skier is turning (Bere et al., 2011). With this rate of knee injury, it would be worthwhile looking into how the injuries
occur and how to prevent future injuries to prolong the career of the athlete and help make skiing a safer sport in general. The main points of injury in the knee include a partial or full tear of the Anterior Cruciate Ligament (ACL), and taking shear stress off of the ACL will help reduce the chances of injury. The main mechanism of anterior cruciate ligament injury in World Cup alpine skiing appeared to be a slip-catch situation where the outer ski catches the inside edge, forcing the knee into internal rotation and valgus (Bere et al., 2011). This and other similar situations leading to the skier losing control usually occurs during the turn out of the fall line of the slope. The fall line on a ski slope is the route leading directly down any section of slope. This causes a loss of balance and pressure is removed from the outer ski in the turn and the edge of the ski catches into the snow. This causes an extreme knee joint compression, knee valgus, and internal rotation which applies excessive stress on the ACL (Bere et al. 2013). Other slip-catch rotations that may occur during skiing include landing back-weighted and dynamic snowplow. All these cases are due to loss of balance of the skier that could be caused by multiple issues. One of the factors that lead to situations that may cause injury in the knee joint could be fatigue in the muscles surrounding the joint. There may be an indirect correlation between muscle fatigue and risk of injury with observation showing that most injuries occur in the last quarter of a race when fatigue is most evident, but it has yet to be properly statistically proven to be a direct causation (Spörri, Kröll, Gilgien, & Müller, 2017). Previous studies support that there are four current risk factors that may influence the risk of injury. These include insufficient core strength or core strength imbalance, differences in the type of injury due to the sex of the skier, the skill level of the skier, and genetic predisposition of knee joint anatomy and structure (Spörri, Kröll, Gilgien, & Müller, 2017). The skiers who have insufficient core strength or core strength are at risk because core
strength plays an important role in keeping balance while skiing. If fatigue happens in the core muscles this could lead to the center of balance being in an incorrect location with respect to the skis and cause the skier to slip out and cause injury with improper form. An example of improper form that could cause a slip out event include the skier leaning back and transferring the force due to body weight to the rear edge of the skis that cause the ski edge to slip in the front and potentially catch in the snow. Gender studies support that males were at higher general risk of injury, but also support that gender has no significant effect on ACL injury rates (Pujol N, Blanchi MP, Chambat P., 2007). Additionally, there is a significant increase in ACL injury rates for skiers who are genetically disposed to have weaker tendons and ligaments. Other significant observations include subjects with previous injuries tended to have a higher valgus angle than people who were uninjured. This supports the hypothesis that having a greater valgus angle leads to a higher risk of injury of the ACL (Bere et al., 2011).

2.2 Potential Injury Prevention Methods

More personalized ways of injury prevention could be developed in order to help protect athletes during skiing while racing and practice. Injuries sustained during skiing are like other non-contact ACL injury mechanisms in team sports so methods developed can be used to help assess risk of injury or reinjuring. A method was introduced to do a biomechanical screening that assessed neuromuscular control and valgus loading during jump landings that aimed at predicting risk of ACL injury (Quatman CE, Hewett TE., 2007). However, this method would only be useful in situations such as jumps during ski racing. Another method that could be used that might be more applicable to a majority of alpine ski racing would be the hamstrings to quadriceps ratio (H/Q) that can be measured to help with understanding the relationship to
these and injury prevention. The thought process for the ratio is that having strong hamstring muscles would reduce or prevent an anterior shift of the tibia relative to the femur during skiing that may lead to ACL injury (Brucker PU et al, 2011). A preferred ratio for H/Q has not been found, but a better analysis of the peak-to-peak H/Q was analyzed that could be used as a screening approach. This peak-to-peak ratio could provide a better insight to injury during alpine skiing because most injuries to the ACL occur in a very short period of time, about 60 milliseconds, that can open new possibilities in screening (Jordan MJ, Aagaard P, Herzog W., 2015). Previous studies have shown that skiers with ACL injuries had a higher H/Q ratio (46%-95%) when compared to a healthy knee H/Q ratio (42%-85%) (Kannus P., 1988). It was found that because of the substantial risk of injury, the importance of quadriceps muscle strength for ski performance and hamstring muscle strength is important for proper ACL operation. The muscle balance is also key to ensuring that the ACL is working properly and has a reduced risk of injury.

2.3 Knee Physiology

The knee joint is one of the most unstable joints in the human body that may be at risk of being injured more easily than other body parts when activity is done. The knee joint is a complex modified hinge joint with the greatest range of motion in flexion and extension in the sagittal plane as well as varus and valgus about the frontal plane (Abulhasan, J. F., & Grey, M. J., 2017). The knee consists of two bony articulations between the femur and tibia, the femorotibial joint, that bears the greatest amount of body weight while the knee is in use, and the patella and femur, the patellofemoral joint, which allows for a smooth transfer of forces created with the contraction of the quadriceps and biceps femoris muscle. With these joints the knee has six degrees of freedom in range of motion with the ability to move in the sagittal,
transverse, and frontal planes, as well as extension, internal rotation, and varus and valgus stress. The stabilization from the knee ligaments and a secondary stabilization through muscles around the knee joint work together simultaneously to keep the knee functioning reliably. When the ligaments are at risk of being injured, muscle force from muscles attached to tendons take over to provide support in the knee joint. These muscles include the vastus medialis, vastus lateralis, semitendinosus, and the biceps femoris. The key ligaments that act as knee stabilizers include the anterior cruciate ligament (ACL), the posterior cruciate ligament (PCL), the medial collateral ligament (MCL), and the lateral collateral ligament (LCL). The ACL is the main ligament that has increased strain in sports and other high intensity activities because it primarily acts to resist anterior and rotational displacement of the tibia relative to the femur which is where many of the forces are applied during activities. The ACL is the main stabilizer of the knee making up about 85% of the knee stabilization (Abulhasan, J. F., & Grey, M. J., 2017). The ACL experiences the least strain between 20 degrees to 30 degrees under knee motion in flexion.

![Anatomical Appearance](image)

**Figure 2.** Anatomical Appearance. A. Normal appearance of the knee joint from the lateral view. B. Normal appearance of the knee joint from the anterior view.
Understanding the general alignment of the knee is also very important in knowing if a person is at greater risk of injury. If a person is either bow-legged (varus) or knock-kneed (valgus) will often determine how someone will either be at higher risk of injury and how they recover from ligamentous injuries as shown in figure 3.

**Figure 3.** A. A photo depicting a normal knee alignment. B. A photo depicting a valgus knee alignment. C. A knee depicting a varus knee alignment.
METHODS

3.1 Participants

Table 1. Participants for Skier’s Edge Data for type of workout, gender, age, height, and weight. The three types of workouts include a standard ski conditioning workout, elliptical workout, and Skier’s Edge workout.

<table>
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<tr>
<th>Subject Number</th>
<th>Type of Workout</th>
<th>Gender</th>
<th>Age</th>
<th>Height (inches)</th>
<th>Weight (lbs)</th>
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<tbody>
<tr>
<td>1</td>
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<td>Female</td>
<td>23</td>
<td>69</td>
<td>145</td>
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<td>2</td>
<td>Conditioning Workout</td>
<td>Female</td>
<td>25</td>
<td>67</td>
<td>145</td>
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<tr>
<td>3</td>
<td>Conditioning Workout</td>
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<td>22</td>
<td>70</td>
<td>171</td>
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<tr>
<td>4</td>
<td>Skier's Edge</td>
<td>Male</td>
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<td>255</td>
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<tr>
<td>5</td>
<td>Skier's Edge</td>
<td>Female</td>
<td>20</td>
<td>62</td>
<td>115</td>
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<td>Male</td>
<td>23</td>
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<td>Skier's Edge</td>
<td>Male</td>
<td>24</td>
<td>74</td>
<td>260</td>
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</table>

The participants included 9 male skiers (22±3 years old, 70.56±3.44 inches, 206±54 lbs.) and 6 female skiers (22±4 years old, 66.25±3.25 inches, 148±72 lbs.). The participants were then
informed of what the study entailed and were asked to sign a consent form that was approved by the California Polytechnic State University Human Subjects Institutional Review Board. Each subject was then given a Physical Activity Readiness Questionnaire (PAR-Q) to show that the subjects did not have any previous injury, surgery, or current lower limb pain and were willing and able to complete the study.

3.2 Method of Data Collection

The Biopac MP 160 hardware was used to collect Electromyography (EMG) and kinetic data. The EMG data was collected using the BIONOMADIX 2 Channel Wireless EMG Amplifier. The EMG wireless sensor 2 channels, A and B, with positive, negative and ground wires were attached to 9 silver chloride surface electrodes (Part #: EL503) on each leg. The electrode placements on each leg were found using SENIAM sensor locations (Hermens HJ, et al., 2019).
Positive and negative surface electrodes were placed on the vastus lateralis, vastus medialis, semitendinosus, and biceps femoris with the wires of the EMG amplifier module attached to the surface electrodes placed on all muscles stated and one on each patella to serve as a ground for any other signal originating somewhere other than the muscles being recorded. The maximum voluntary contraction (MVC) was recorded to normalize the regular EMG data so statistical analysis can be done on the data. Kinetic data was collected using the Biopac
heel-toe strike force transducers (Part #: TSD111A) connected to an amplifier in the Biopac MP-160 system. Heel-toe force data was collected simultaneously with the last exercise done with initial and final EMG collection using the force transducers attached to the feet on the bottom of the participants' shoes at the heel and toe locations. This collected both force data for the left and right feet but also collected the heel and toe force data as the participant sways back and forth. Kinematic data was collected by taking images of each participants’ legs as they stood with bare feet facing forward and shoulder-length apart on the coronal plane as well as an image of each participants’ with the heels together and feet turned out in an external rotation as shown in Figure 6 in the transverse plane. This was used to find the subsequent valgus or varus angles in the knee joint and that was used for relative moment calculations of the combined force and angle data. The knee joint angles were found with the protractor application provided on the Microsoft application store.

3.3 Study Setup

3.3.1 Initial Data collection

First, each participant took part in an initial data collection that used the Biopac MP 160 sensor package for the collection of EMG and kinetic data. The initial data collection was done on the Skier’s Edge T7 ski conditioning machine with attached assistant coach balance bar. The Skier’s Edge had four settings for level of resistance on the elastic band 1 being least resistance and 4 being the most and the Skier’s Edge was set to level 2, or average resistance. The pivoting foot platforms were set to the middle setting for normal skiing position. The participants then were given a short introduction to the use of the machine to get them familiarized. Surface electrodes were placed in the muscles to collect EMG data during the
initial data collection. The study was conducted in sequence as stated. The EMG sensor was attached to the left leg and wires for the positive, negative and ground for channel A and B were first attached to the surface electrodes on the vastus medialis and vastus lateralis respectively. The participant was asked to complete a maximum voluntary contraction (MVC) that entailed operation of the Skier’s Edge at the most to their ability for a period of 10 seconds. The participant then had a rest period of a minute to ensure that they were not fatigued. The participant then completed 10 seconds of normal operation of the Skier’s Edge to collect EMG data for the muscle groups. This process of MVC and normal operation was repeated for the left leg biceps femoris and semitendinosus muscle group. This was then repeated on the vastus medialis and vastus lateralis muscle group, and biceps femoris and semitendinosus muscle group for the right leg. On the final operation of the Skier’s Edge, the participant then had heel-toe strike force transducers taped onto the feet to collect both left and right force data. Each participant was then photographed to collect a coronal plane view of the knee joint and a transverse photograph of the feet with heels together and feet turned out with an external rotation as much as the participant could do comfortably as shown in figure 6. This was to collect the kinematic data for valgus and varus angle in the knee joint.
Figure 5. Knee valgus angle data collection. A. Right leg knee valgus angle. B. Left leg knee valgus angle. C. External rotation of knee angle.
3.3.2 Time Study

The next portion of the study included a four-week duration workout session for each participant. The participants were split up into three groups: Skier’s Edge workout, elliptical workout, and traditional ski conditioning workout. The groups were randomly and evenly selected for each participant separating them at the start into groups at the start before any exercise. Each group then was instructed to complete the following workouts for a set period. The Skier’s Edge workout group (group 1) rode the Skier’s Edge at the level 2 setting with the foot platforms set to the standard skiing position for a duration of 10 minutes three times a week for a period of four weeks. The participant could take breaks when needed in the duration until they reached the 10-minute duration as recommended by the Skier’s Edge Company (G. Miller, Phone Interview, May 18, 2019). The elliptical riders (group 2) rode the Precor EFX CrossRamp 833 elliptical set at the middle setting of resistance and the angle of the internal ramp inside the elliptical set to 30° as shown in figure 6 for 15 minutes three times a week for a period of four weeks, and the traditional workout group (group 3) completed a workout consisting of several leg and balance workouts three times a week for a period of four weeks. The traditional workout as shown in Table 2 was the workout recommended by the University of Colorado Hospital to prepare skiers for the ski season (Ucdenver.edu, 2003).
**Figure 6.** Precor EFX CrossRamp 833 set to the medium resistance setting and the internal ramp set to 30°. [Photo of EFX CrossRamp 833] Retrieved from https://www.precor.com/en-us/commercial/cardio/ellipticals/efx-833-elliptical-fitness-crosstrainer

<table>
<thead>
<tr>
<th>Table 2. Traditional ski conditioning workout from University of Colorado Hospital completed by group 3 in study.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Workout</strong></td>
</tr>
<tr>
<td>Squats with free weights, leg press machine, or your own body weight</td>
</tr>
<tr>
<td>one-legged squats with 45 to 90 degrees knee flexion</td>
</tr>
<tr>
<td>Standing lunges(forward)</td>
</tr>
<tr>
<td>Standing Lunges (Diagonal)</td>
</tr>
<tr>
<td>Balance on one leg, move the other leg out and in</td>
</tr>
<tr>
<td>Balance on one leg, move the other leg back and forth</td>
</tr>
<tr>
<td>Standing or lying leg lifts</td>
</tr>
</tbody>
</table>
3.3.3 Final Data Collection

The final data collection was completed after the four-week duration workout programs and was identical to the initial data collection. The Skier’s Edge was set to the level 2 medium resistance setting and the foot distance apart was set to the normal ski setting. Each subject returned to the Skier’s Edge to all be reminded of the operation of the device before starting the final data collection. Each participant then had surface electrodes placed on the vastus medialis, vastus lateralis, biceps femoris, and semitendinosus for both the left and right legs. The same process of collecting MVC by having the participant use the Skier’s Edge at their max capability and then normal operation of the Skier’s Edge of a duration of 10 seconds per muscle was completed for each muscle group. During the final normal operation for the right leg biceps femoris and semitendinosus muscle group, heel-toe strike force transducers were attached to the participant’s shoes to collect force data. The data was then saved for further analysis in the Aqcknowledge 5.0 software.

![Figure 7. EMG data collection process for both left and right legs of each participant.](image)

3.3.4 Data Analysis

Statistical analysis was performed on the data collected in order to understand if there was a significant difference in any of the data comparisons. The data was collected by hand
selection of each individual peak value recorded into the Acqknowledge 5.0 software for all EMG data and force data. This included the collection of EMG signal peaks in millivolts (mV), the peak value for the MVC for each muscle group in mV and the integral of each peak in mV-seconds as well as the time duration of each peak in seconds. This was then input into Excel spreadsheets for further analysis. The comparison of EMG data was done for the average level of amplitude of data rectified using a root mean square (RMS) function. The EMG data was then normalized in two different ways, by dividing the peak values by the MVC to give a percent MVC and with the collection of the integral of the curves divided by time. The hamstring over quadricep muscle ratios (H/Q) were calculated using the average peak values of the vastus medialis over the semitendinosus values for both the pre workout and post workout MVC percent and integral divided by time normalized values. All analysis was done on Excel using the Analysis ToolPak Add-in and JMP Pro 14. The analysis done on these two types of values included regression models to test the hypothesis stated earlier. The Y value in the equation, shown in eq. (1) is a percentage of the post workout and pre workout data collection difference over the post workout as shown in eq. (2). The X variables included in the equation had three levels being tested for the three types of workouts. The levels were traditional workout, elliptical workout, and Skier’s Edge workout. This analysis shows if there was a significant difference in muscle activity in any of the workout groups for pre and post workout. The second analysis was done on a relative measure of valgus moment. The relative measure of valgus moment was found by using the equation shown in eq. (3). The measured knee angle for each participant was subtracted from 180 degrees to give the amount the knee differed from vertical. This value was then multiplied by the average peak toe force voltage from the force transducer, in mV, of each participant to give a relative measure of the valgus
moment in the knee of each participant for the pre and post workout. A regression model was
done on this data to analyze the difference between workout methods and the increase or
decrease of valgus moments. The Y intercept as shown in the eq. (4) is the relative measure of
the valgus angle for each participant. The X variables include the workout types of the
elliptical and the traditional ski workout as well as the dominant leg with the skier’s edge
being the baseline. This was to find if there was a significant difference between the relative
valgus moments when compared to each workout and between the dominant and
nondominant leg.

\[
\text{Eq. (1)} \quad Y = \beta_0 + \beta_{\text{ell}}X_{\text{ell}} + \beta_{\text{wo}}X_{\text{wo}}
\]

\[
\text{Eq. (2)} \quad Y = \frac{X_{\text{postworkout}} - X_{\text{preworkout}}}{X_{\text{preworkout}}}
\]

\[
\text{Eq. (3)} \quad Y = (180^\circ - X_{\text{valgus}}) \cdot F_{\text{Toe}}
\]

\[
\text{Eq. (4)} \quad Y = \beta_0 + \beta_{\text{ell}}X_{\text{ell}} + \beta_{\text{wo}}X_{\text{wo}} + \beta_{\text{dom}}X_{\text{dom}}
\]

Eq. (1) and Eq. (2) are the regression model
and pre and post workout percentage for
EMG data statistical Analysis.

Eq. (3) and Eq. (4) are the relative valgus
moment and regression model for the
relative valgus angle statistical analysis.

RESULTS

4.1 Valgus Angle and Force Data Regression Model

4.1.1 Initial Valgus Angle and Force data Regression Model

A preliminary linear regression was calculated to predict ACL injury risk based on a relative
measure of initial valgus moments between participants in different workout groups. A non-
significant regression equation was found (F(3, 26) = 0.300918547, p < .824), with an R^2 of
.033. Participants’ ACL injury risk is equal to 10.85 - 0.762X_{\text{ell}} - 0.686X_{\text{ell}} - 1.381X_{\text{dom}}
with baseline being the Skier’s Edge data.
Table 3. Linear regression model for relative valgus moment, pre workout initial data for elliptical workout, traditional ski conditioning workout, dominant leg and Skier’s Edge data as the baseline.

### Summary of Fit

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<td>Observations (or Sum Wgts)</td>
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### Parameter Estimates

| Term        | Estimate | Std Error | t Ratio | Prob>|t| |
|-------------|----------|-----------|---------|------|
| Intercept   | 10.855931| 2.345074  | 4.63    | <.0001* |
| Xell[0]     | 0.762097 | 2.345074  | 0.32    | 0.7478 |
| Xworkout[0] | -0.686959| 2.345074  | -0.29   | 0.7719 |
| Xdom[0]     | -1.381532| 1.914745  | -0.72   | 0.4770 |

**Figure 8.** A. The actual by predicted plot for the model. B. Residual Normal plot showing a normal distribution for the data. C. Residual by Predicted plot showing equal variance.
4.1.2 Final Valgus Angle and Force data Regression Model

A preliminary linear regression was calculated to predict ACL injury risk based on a relative measure of initial valgus moments between participants in different workout groups. A non-significant regression equation was found (F(3, 26) = .721617971, p < .548), with an $R^2$ of .076. Participants’ ACL injury risk is equal to $9.944 - 2.166X_{ell} + 0.964843X_{workout} - 1.593381X_{dom}$ with baseline being the Skier’s Edge data.

Table 4. Linear regression model for relative valgus moment, post workout data for elliptical workout, traditional ski conditioning workout, dominant leg and Skier’s Edge data as the baseline.

<table>
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<tr>
<th>Source</th>
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<td>0.5482</td>
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Parameter Estimates

| Term            | Estimate | Std Error | t Ratio | Prob>|t| |
|-----------------|----------|-----------|---------|-------|
| Intercept       | 9.9447029| 1.983747  | 5.01    | <.0001*|
| Xell[0]         | 2.1661752| 1.983747  | 1.09    | 0.2849 |
| Xworkout[0]     | 0.964843 | 1.983747  | 0.49    | 0.6308 |
| Xdom[0]         | -1.593381| 1.619723  | -0.98   | 0.3343 |
Figure 9. A. The actual by predicted plot for the model. B. Residual Normal plot showing a normal distribution for the data. C. Residual by Predicted plot showing equal variance.

4.2. Hamstring to Quadricep Ratio for Pre and Post Workout Percent Change

4.2.1. Left Leg Analysis of Pre and Post Workout MVC Percentage Change

A preliminary linear regression was calculated to predict ACL injury risk based on an MVC normalized H/Q ratio between participants’ left leg in different workout groups. A non-significant regression equation was found (F(2,11) = 0.643442669, p < .544), with an R^2 of .104. Participants’ ACL injury risk is equal to 0.754 + 0.277X_{cell} - 0.143X_{workout} with baseline being the Skier’s Edge data.
Table 5. Linear regression model for ACL injury risk based on an MVC% normalized H/Q ratio between participants’ left leg in different workout groups.

**Summary of Fit**

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**Analysis of Variance**

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**Parameter Estimates**

| Term        | Estimate | Std Error | t Ratio | Prob>|t| |
|-------------|----------|-----------|---------|------|
| Intercept   | 0.7541786| 0.383473  | 1.97    | 0.0750|
| Xell[0]     | 0.2775027| 0.361542  | 0.77    | 0.4589|
| Xworkout[0] | -0.143744| 0.383473  | -0.37   | 0.7149|

---

**Figure 10.** A. The actual by predicted plot for the model. B. Residual Normal plot showing a normal distribution for the data. C. Residual by Predicted plot showing equal variance.
4.2.2. Right Leg Analysis of Pre and Post Workout MVC Percentage Change

A preliminary linear regression was calculated to predict ACL injury risk based on an MVC normalized H/Q ratio between participants’ right leg in different workout groups. A non-significant regression equation was found (F(2,11) = 0.19059877, p < .829), with an R² of .033. Participants’ ACL injury risk is equal to 0.222 - 0.005X_{cell} + 0.229X_{workout} with baseline being the Skier’s Edge data.

Table 6. Linear regression model for ACL injury risk based on an MVC% normalized H/Q ratio between participants’ right leg in different workout groups.

Summary of Fit

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<tr>
<th>Source</th>
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<th>RSquare Adj</th>
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<th>Mean of Response</th>
<th>Observations (or Sum Wgts)</th>
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Analysis of Variance

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Parameter Estimates

| Term               | Estimate | Std Error | t Ratio | Prob>|t[|
|--------------------|----------|-----------|---------|------|
| Intercept          | 0.2227118| 0.426166  | 0.52    | 0.6116|
| Xcell[0]           | -0.00508 | 0.401793  | -0.01   | 0.9901|
| Xworkout[0]        | 0.2294611| 0.426166  | 0.54    | 0.6010|
4.2.3. Left Leg Analysis of Pre-Workout Over Post Workout EMG Integral

Normalized Percentage

A preliminary linear regression was calculated to predict ACL injury risk based on integral over time normalized H/Q ratio between participants’ left leg in different workout groups. A non-significant regression equation was found (F(2,11) = 0.722369822, p < .507), with an $R^2$ of .116. Participants’ ACL injury risk is equal to $0.639 - 0.310X_{\text{cell}} + 0.152X_{\text{workout}}$ with baseline being the Skier’s Edge data.
Table 7. Linear regression model for ACL injury risk based on an integral divided by time normalized H/Q ratio between participants’ left leg in different workout groups.

Summary of Fit

| Term                    | Estimate | Std Error | t Ratio | Prob>|t| |
|-------------------------|----------|-----------|---------|-----------------|
| Intercept               | 0.6394351| 0.398874  | 1.60    | 0.1372          |
| Xell[0]                 | -0.310011| 0.376062  | -0.82   | 0.4272          |
| Xworkout[0]             | 0.152704 | 0.398874  | 0.38    | 0.7091          |

Analysis of Variance

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Parameter Estimates

Figure 12. A. The actual by predicted plot for the model. B. Residual Normal plot showing a normal distribution for the data. C. Residual by Predicted plot showing equal or unequal variance.
4.2.4. Right Leg Analysis of Pre-Workout Over Post Workout EMG Integral

Normalized Percentage

A preliminary linear regression was calculated to predict ACL injury risk based on integral over time normalized H/Q ratio between participants’ right leg in different workout groups. A non-significant regression equation was found ($F(2,11) = 0.319269503, p < .733$), with an $R^2$ of .054. Participants’ ACL injury risk is equal to $0.611 + 0.212X_{ell} - 0.020X_{workout}$ with baseline being the Skier’s Edge data.

Table 8. Linear regression model for ACL injury risk based on an integral divided by time normalized H/Q ratio between participants’ right leg in different workout groups.

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<th>Analysis of Variance</th>
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Parameter Estimates

| Term          | Estimate  | Std Error  | t Ratio | Prob>|t| |
|---------------|-----------|------------|---------|------|
| Intercept     | 0.6113515 | 0.334452   | 1.83    | 0.0948|
| Xell[0]       | 0.2126742 | 0.315325   | 0.67    | 0.5139|
| Xworkout[0]   | -0.020063 | 0.334452   | -0.06   | 0.9532|
Figure 13. A. The actual by predicted plot for the model. B. Residual Normal plot showing a normal distribution for the data. C. Residual by Predicted plot showing equal variance.

DISCUSSION

5.1 Muscle Activity and Force Changes

The hypothesis being addressing in this study is that if a novice skier or expert skier use the Skier’s Edge trainer then the a decrease in the vastus lateralis over vastus medialis and or an increase in semitendinosus over vastus medialis will be leading to a reduction in shear forces of the valgus moment on the knee joint and ACL due to lesser fatigue of muscle leading to improper form and balance. A change in muscle activity of usage of the Skier’s Edge will
occur with the use of the Skier’s Edge over time. During the study, a comparison was made with the different participants before and after and their respective workouts. The comparisons made looked at kinematic, kinetic and EMG data that could give a greater knowledge of what types of workouts can be used for the reduction of ACL injury. With this data, a statistical analysis was done to find if there was any significant data that showed if either the lateral movement workout achieved with Skier’s Edge or the use of more linear workouts such as the elliptical or a traditional workout would be a better choice for ACL injury reduction. The data collected was separated and analyzed in different sections of focus such as the knee valgus angle and relative force values to attempt to see if there was a difference in relative valgus moments caused by the difference in force or valgus angle compared between the groups. The other section of data that was analyzed between the different groups were the hamstring to quadricep ratio found using EMG data showing muscle activity. This analysis was also done between legs to see if there was a difference between groups to see muscle activity of one leg over the other showing if participants had been better at balancing or not.

5.1.1. Pre-Workout Relative Valgus Moment Analysis

The data for the relative valgus moment was analyzed statistically by completing a regression model and a one-way analysis of variance between the Skier’s Edge, elliptical, and a traditional workout to find if any groups had a significantly different value. Another analysis between the dominant leg of each participant was completed to see if there was a significant difference in relative valgus moments. Looking at the initial data for relative valgus moment in table 3 it shows that there are no significant differences between any of the workout types.
and the Skier’s Edge. This can be seen in the p-values for each variable associated with the data for each workout type $X_{\text{ell}}$ for elliptical workout and $X_{\text{workout}}$ for the traditional ski conditioning workout. The p-value for $X_{\text{ell}}$ was $(P = 0.7478 > 0.05)$ and the p-value for $X_{\text{workout}}$ was $(P = 0.7719 > 0.05)$. These values show that there is no significant difference of values when compared to the Skier’s Edge data. This is the initial data this shows that all participants had similar data when they started. The value for $X_{\text{dom}}$ is $(P = 0.4770 > 0.05)$ showing that there was no significant difference between dominant and non-dominant leg between participants as compared to the Skier’s Edge. The normal quantile plot in section B of figure 8 shows that the data can be assumed to have a normal distribution because it does not differ greatly from the line and section C shows that there are no patterns in the residual by predicted plot meaning that the data can be assumed to have normal even variance.

5.1.2 Post Workout Relative Valgus Moment Analysis

The data for the relative valgus moment final post workout was analyzed statistically to see if after the four-week period any significant differences occurred in the data between the elliptical or traditional ski workout as well as any changes in the dominant leg as compared to the Skier’s Edge data. It is shown in table 4 that the p-value for $X_{\text{ell}}$ was $(P = 0.2849 > 0.05)$ and the p-value for $X_{\text{workout}}$ was $(P = 0.6308 > 0.05)$. The p-value for $X_{\text{dom}}$ is $(P = 0.3343 > 0.05)$. None of the p-values were less than 0.05 meaning that there was no significant difference between the different workout methods when compared to the Skier’s Edge data. The workouts did not cause enough of a change to change the values for relative valgus moment dramatically. This means that the mean forces in the heel-toe transducers stayed around the same for each workout. With that stated it shows that the mean forces in the knee
cannot be proven to be significantly different and that they stayed relatively the same between each workout group as compared to the Skier’s Edge. The other variable in the data that could have changed was the measured valgus angle in the knee but based on the data it cannot be proven that there was a change in the mean valgus angle values. The mean values for relative valgus moment in the knee for the dominant leg of each participant as was shown to not have a significant difference. This means there is not enough evidence to show there was a significant difference between the mean values. The mean values not being significantly different shows that there is not enough evidence to show that any of the participants got stronger in the dominant leg only meaning that the balance of muscle training was potentially equal between legs. The normal quantile plot, or section B, of figure 9 shows that the data can be assumed to have a normal distribution because it does not differ greatly from the zero line. Section C shows that there is equal variance of means in the data because there are no patterns to be found in the residual by predicted plot.

5.1.3 Relative Valgus Moment Analysis

The data shows that there was no significant difference between any of the different workout groups but looking at the data there could be potential trends that could lead to a more conclusive answer if more testing was completed. The trends being shown in the data show that the p-value for the elliptical workout group was \( P = 0.2849 \) which was the lowest of the p-values for the post workout. This could mean that there might be a difference in the mean values for the elliptical workout when compared to the Skier’s Edge. With the positive change in the regression coefficient between the pre and post workout. That could mean that either the Skier’s Edge were having a decrease in valgus moment in the knee or that the elliptical
workout group was having an increase in valgus moment in the knee. It can also be shown that all the workouts helped in keeping the legs balanced because the p-value for the post workout dominant leg was $P = 0.3343$ and the regression coefficient estimate was $X_{dom} = -1.59$. This could be a trend saying that there was an overall decrease in valgus moment in the dominant leg as compared to the Skier’s Edge data. There is a 70% confidence that the Skier’s Edge and traditional workout had lower relative valgus moments than the elliptical workout. There was not a high enough confidence level to show any difference between Skier’s Edge and the traditional workout.

5.2 EMG Data MVC Analysis

5.2.1 EMG Data MVC Left Leg Analysis

The data in the EMG data was first normalized with the max voluntary contraction of each participant. The data for the pre and post workout percent change included the different workout groups $X_{ell}$ and $X_{workout}$ as compared to the Skier’s Edge workout data. The p-value for $X_{ell}$ was ($P = 0.4589 > 0.05$). This means that there was no significant difference for the mean value of the elliptical workout H/Q ratio in the left leg for the pre and post workout percentage change when compared to the Skier’s Edge data. The p-value for $X_{workout}$ was ($P = 0.7149 > 0.05$). This means that there was no significant difference in the mean value of the traditional ski conditioning workout H/Q ratio in the left leg for the pre and post workout percentage change when compared to the Skier’s Edge data. Overall, this means that there was no significant difference in the mean value for H/Q ratios for the different workouts when compared to the Skier’s Edge. The normal quantile plot, or section B, of figure 10 shows that the data can be assumed to have a normal distribution because it does not differ greatly from
the zero line. Section C shows that there is equal variance of means in the data because there are no patterns to be found in the residual by predicted plot. The H/Q ratio in the left leg may not have had a significant difference but looking at the data there is some trends that occur that may lead to more testing the future. In the left leg data, there is a positive change in the estimated regression coefficient for the elliptical data that could mean that the H/Q ratio was increasing pre to post when compared to the Skier’s Edge data. As previous studies show, having an increased H/Q ratio is a method of potential reduction in ACL injury over time (Kannus P., 1988). This means that the use of the elliptical may have a better ability to prevent ACL injury over time as muscle strength increases as compared to the Skier’s Edge. In table 7 we can make a 55% confidence statement that the H/Q ratio decreases with Elliptical training. There was no difference between the Skier’s Edge and the traditional ski workout.

5.2.2 EMG Data MVC Right Leg Analysis

The data in the right leg was also normalized using the MVC for each participant. The data for the right leg for the pre and post percent change included the variables for the different workouts $X_{ell}$ and $X_{workout}$ as compared to the Skier’s Edge. The p-value for $X_{ell}$ was ($P = 0.9901 > 0.05$) meaning that there was no significant difference in the pre and post workout percent change of the H/Q ratios for the elliptical workout when compared to the Skier’s Edge data. The p-value for $X_{workout}$ was ($P = 0.6010 > 0.05$) meaning that there was no significant difference in the pre and post workout percentage of the H/Q ratios for the traditional ski conditioning workout when compared to the Skier’s Edge data. This shows that overall there was no significant difference in pre and post percentages for H/Q ratios when compared to the
Skier’s Edge H/Q ratios. The normal quantile plot, or section B, of figure 11 shows that the data can be assumed to have a normal distribution because it does not differ greatly from the zero line. Section C shows that there is equal variance of means in the data because there are no patterns to be found in the residual by predicted plot. Trends in the data however might lead to more testing in the future regarding this topic. Looking at the lowest p-value shows that the traditional ski conditioning workout or X_{workout} has a positive change in the right pre to post workout percent change of the H/Q ratio when compared to the Skier’s Edge. This could mean that the traditional workout raises the H/Q ratio more than the Skier’s Edge workout. The increase of the H/Q ratio could lead to a reduced risk of ACL injury in the future as per previous a previous study claims (Kannus P., 1988).

5.3 EMG Data Integral Analysis

5.3.1 EMG Data Left Leg Integral Analysis

The EMG data was analyzed in a different way normalizing the data with the integral of each curve of muscle activity being divided by the change in time for the duration of the activity. The data for the pre and post workout percent change included the different workout groups for the elliptical workout and the traditional ski conditioning workout, or X_{ell} and X_{workout} respectively, as compared to the Skier’s Edge workout data for the left leg of each participant. The p-value for X_{ell} was (P = 0.4272 > 0.05) meaning that there is not a significant difference in the mean value for H/Q ratios for the pre and post workout percent changes between the elliptical workout and the Skier’s Edge. The p-value for X_{workout} was (P = 0.7091 > 0.05) meaning that there is not a significant difference in the mean values for H/Q ratio pre and post workout percent change as compared to the Skier’s Edge. Overall, this means that there is no
significant difference between the mean values for the H/Q ratio pre and post workout percent change of the elliptical workout and traditional ski conditioning workout. The normal quantile plot, or section B, of figure 12 shows that the data can be assumed to have a normal distribution because it does not differ greatly from the zero line. Section C shows that there is equal variance of means in the data because there are no patterns to be found in the residual by predicted plot. Looking at the trends however may show more that could be focused on in a later study. The lowest p-value for the left leg integral data is for the elliptical workout with P = 0.4272. The regression model coefficient estimate is negative meaning potentially that the H/Q ratio is lower than the Skier’s Edge meaning that the Skier’s Edge may potentially be a better workout for raising the H/Q ratio when compared to the elliptical data.

**5.3.2 EMG Data Right Leg Integral Analysis**

The data for the pre and post percent change for the H/Q ratio included the different workout groups which are the elliptical and traditional ski conditioning workout, or X_{ell} and X_{workout} respectively, as compared to the Skier’s Edge workout data for the right leg of each participant. The p-value for X_{ell} was (P = 0.5139 > 0.05) meaning that there was not a significant difference in the mean values for the H/Q ratio pre and post workout percent change for the elliptical data as compared to the Skier’s Edge. The p-value for X_{workout} was (P = 0.9532 > 0.05) meaning that the mean values for the H/Q ratio pre and post percent change was not significantly different for the traditional ski conditioning workout when compared to the Skier’s Edge. Overall, this means that each workout H/Q ratio pre and post percent change were not significantly different as compared to the Skier’s Edge. The normal quantile plot, or section B, of figure 13 shows that the data can be assumed to have a normal distribution.
because it does not differ greatly from the zero line. Section C shows that there is equal variance of means in the data because there are no patterns to be found in the residual by predicted plot. Looking at the trends in the data could show what to focus on in next steps for a new study. The lowest p-value for the right leg H/Q ratio pre and post percent change is for the elliptical, which is $P = 0.5139$. The regression coefficient estimation is a positive change as compared to the Skier’s Edge meaning that the elliptical workout could lead to a higher H/Q ratio.

CONCLUSION

6.1 Limitations, Assumptions and Error

The limitations for this study include limited funding and limited EMG sensor channels in the Biopac MP 160. The limited funding made it more difficult to secure better sensor technology to increase the accuracy of the measurements for force and EMG data as well as kinematic data. Being able to measure the movement of the human body would have allowed for a better model of the knee in motion and given the direction of the force at the peak force measurement. The limited channels in the Biopac MP 160 for EMG data collection made it difficult to collect the data for each muscle group simultaneously. This led to more variability in the data collection as it would take multiple times to be able to collect all the muscle group activity. Having a more accurate force measurement with sensors showing the ground reaction force as the participant rides the Skier’s Edge would allow for a better data set to accurately represent forces applied to the knee. The assumptions made for this study included that the small sample size would still represent the normal population with a normal distribution, it was also assumed that all participants had some skiing experience as reported in an initial
question before allowing them to participate in the study. It was also assumed that the H/Q ratio was an indicator to a potential for a reduced risk for ACL injury. Error points could include issues with human error due to improper placement of surface electrodes leading to weak or distorted signals for EMG data. Other error points could be improper placement of force transducers on the feet leading to inaccurate force data.

6.2 Conclusion and Future Study Thoughts

In this study, a biomechanical analysis was completed for the T7 Skier’s Edge ski conditioning machine which included the collection of kinematic, kinetic, and EMG data. A comparison of an elliptical, traditional ski conditioning workout and the Skier’s Edge workout was done to attempt to prove that the Skier’s Edge could provide better conditioning to prevent ACL injury. Participants were separated into equal groups and then had initial data of an EMG for the vastus medialis, vastus lateralis, semitendinosus, and biceps femoris. Force data was also collected using heel-toe force transducers while riding on the Skier’s Edge. Photographs of participants’ knees were measured to find the valgus angle. A month-long workout was completed for each participant in their respective group. A final data collection was completed identically to the initial data collection. An analysis of the data was completed to find a relative valgus moment and statistical analysis of a linear regression model and a one-way ANOVA was run. The factor was workout and levels were workout type.

It was found that there was no significant difference for any of the workouts for the relative valgus moment between the pre and post workout data. The EMG data was normalized with both MVC and integral divided by the time of the curve duration. The H/Q ratio was established by dividing the average value of EMG peak values for the vastus medialis and the
semitendinosus. The pre and post difference percentage was calculated to show the
differences between everyone after the workout was completed. A regression model and a
one-way ANOVA was run on the EMG data with the factor as workout and levels as workout
type. It was found that there was no significant difference between the pre and post workout
percent difference of the H/Q ratio. Looking at the trends in the data it would be advisable to
continue the study and change some of the factors that impacted the outcome of this study.
There were possibilities that the elliptical workout was better in preventing ACL injury based
on the trend of values in this limited study. Potentially increasing the duration of the workouts
or the intensity of the workouts may show that there could be a significant difference in the
outcome of each workout. Focusing on only one workout such as the elliptical compared to
the Skier’s Edge conditioning workout might also reduce variability in the study. The use of
better sensor equipment and motion tracking of the human subjects would also improve the
data accuracy and quality to allow for the best possibility for a significant difference in future
studies. A more in-depth study of subjects who have had a previous ACL injury would be
advisable to test the Skier’s Edge rehabilitation ability. A recommendation of doing other
tests on blood oxygen levels or lactic acid levels in the muscle would help further the field of
safety in skiing. ACL prevention will help improve the safety and satisfaction of skiing for
skier from novice to expert.
REFERENCES/WORKS CITED/BIBLIOGRAPHY


APPENDIX

APPENDIX A.

Data Collection Sheet

NAME: ___________________________ DATE: ___________________________

HEIGHT: _______ in. WEIGHT: _______ lbs. AGE: _______

PHYSICIANS NAME: ___________________________ PHONE: ____________

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

<table>
<thead>
<tr>
<th>Questions</th>
<th>Yes</th>
<th>No</th>
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<tbody>
<tr>
<td>1. Has your doctor ever said that you have a heart condition and that you should only perform physical activity recommended by a doctor?</td>
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<tr>
<td>2. Do you feel pain in your chest when you perform physical activity?</td>
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<td>3. In the past month, have you had chest pain when you were not performing any physical activity?</td>
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<td>4. Do you lose your balance because of dizziness or do you ever lose consciousness?</td>
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<tr>
<td>5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?</td>
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<tr>
<td>6. Is your doctor currently prescribing any medication for your blood pressure or for a heart condition?</td>
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<tr>
<td>7. Do you know of any other reason why you should not engage in physical activity?</td>
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</table>

If you have answered “Yes” to one or more of the above questions, consult your physician before engaging in physical activity. Tell your physician which questions you answered “Yes” to. After a medical evaluation, seek advice from your physician on what type of activity is suitable for your current condition.
# GENERAL & MEDICAL QUESTIONNAIRE

<table>
<thead>
<tr>
<th>Occupational Questions</th>
<th>Yes</th>
<th>No</th>
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</thead>
<tbody>
<tr>
<td><strong>1</strong> What is your current occupation?</td>
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<td><strong>2</strong> Does your occupation require extended periods of sitting?</td>
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<td><strong>3</strong> Does your occupation require extended periods of repetitive movements? (If yes, please explain.)</td>
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<td><strong>4</strong> Does your occupation require you to wear shoes with a heel (dress shoes)?</td>
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<td><strong>5</strong> Does your occupation cause you anxiety (mental stress)?</td>
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<tr>
<th>Recreational Questions</th>
<th>Yes</th>
<th>No</th>
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<tbody>
<tr>
<td><strong>6</strong> Do you partake in any recreational activities (golf, tennis, skiing, etc.)? (If yes, please explain.)</td>
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<td><strong>7</strong> Do you have any hobbies (reading, gardening, working on cars, exploring the Internet, etc.)? (If yes, please explain.)</td>
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<tr>
<th>Medical Questions</th>
<th>Yes</th>
<th>No</th>
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<tr>
<td><strong>8</strong> Have you ever had any pain or injuries (ankle, knee, hip, back, shoulder, etc.)? (If yes, please explain.)</td>
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<td><strong>9</strong> Have you ever had any surgeries? (If yes, please explain.)</td>
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<td><strong>10</strong> Has a medical doctor ever diagnosed you with a chronic disease, such as coronary heart disease, coronary artery disease, hypertension (high blood pressure), high cholesterol or diabetes? (If yes, please explain.)</td>
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<td><strong>11</strong> Are you currently taking any medication? (If yes, please list.)</td>
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APPENDIX B.

INFORMED CONSENT TO PARTICIPATE IN A RESEARCH PROJECT:

“Skier’s Edge: Biomechanical Analysis”

INTRODUCTION

This form asks for your agreement to participate in a research project on a biomechanical analysis of the effects of using the Skier’s Edge ski conditioner on the knee joint and surrounding muscles. Your participation involves two data collections of your biometrics, a month-long ski conditioning exercise program. It is expected that your participation will take approximately 20 minutes for the pre and post data collection, and 15 minutes per session using either the Skier’s Edge, an elliptical, or a traditional ski conditioning workout. Each session will be three days a week for a month duration. The potential risks from this project are considered minimal, as they are similar risks taken for regular usage of workout equipment. If you are interested in participating, please review the following information.

PURPOSE OF THE STUDY AND PROPOSED BENEFITS

- The purpose of the study is to analyze the Skiers Edge to see if skiers at different levels of skill will improve in control of muscle activity in key muscles in the leg and affect forces applied to the anterior cruciate ligament (ACL). A comparison will be completed between the usage of the Skier’s Edge, an elliptical, and a traditional ski conditioning workout.
- Potential benefits associated with the study include a better understanding of muscle strength of muscles and how training muscles for lateral movement in the legs could affect forces on the ACL.

YOUR PARTICIPATION

- If you agree to participate, you will be asked to complete an initial data collection of your muscle activity via electromyography and the use of surface electrodes, force data collection with the use of heel-toe force transducers mounted to the bottom of your shoes, and your knee valgus angle captured with photography. A month-long exercise program of either the use of the Skier’s Edge, an elliptical or a traditional ski conditioning workout will then take place, three days a week for a month. The Skier’s Edge is a ski conditioning workout device focused on non-impact lateral conditioning. This is achieved using lateral weight transfer, balance and agility. The use of the Skier’s Edge involves a back-and-forth motion on a platform with elastic band resistance that simulates the lateral movement in skiing. A final data collection will take place of the same types of data at the end of the month.
- Your participation will take approximately 20 minutes for the pre and post data collection at the beginning of the month and end of the month, and 15 minutes per session using either the Skier’s Edge, an elliptical, or a traditional ski conditioning workout. Each session will be three days a week for a month duration at your own preference.

PROTECTIONS AND POTENTIAL RISKS

- Please be aware that you are not required to participate in this research, refusal to participate will not involve any penalty or loss of benefits to which you are otherwise entitled, and you may discontinue your participation at any time. If you decide to withdraw your participation, you must inform the researcher of your discontinuation of participation and no further data collection will occur. You may omit responses to any questions you choose not to answer. The
The researcher may terminate your participation at any time for the following reasons: failure to state previous injury or failure to complete all sessions required for study.

- The possible risks or discomforts associated with participation in this study include minor muscle discomfort due to usage of Skier’s Edge, elliptical, or traditional ski conditioning workout. This is comparable to any discomfort due to regular workout participation. You will be asked to fill out the Physical Activity Readiness Questionnaire to determine if you are able to be enrolled in the study. There will be two persons always present during the study, one of whom is certified in CPR techniques and the other ready to call medical services if a subject requires it. There may be unforeseeable risks related to your participation.

- Confidentiality of your data will be kept with every subject being assigned a number or letter code that will be used to keep subjects anonymous in any writing or analysis of data. Only the PI, co-PI’s and Faculty Advisor will have access to documents with your name on them.

- Video recordings will be used to capture subject responses or data. The data will be collected with a digital camera and stored on a password protected computers. The data will be kept, and some data may be used in promotional videos for Skier’s Edge.

- Identifying information might be removed from identifiable private information and that, after such removal, the information could be used for future research studies or distributed to another researcher for future studies without additional informed consent.

RESOURCES AND CONTACT INFORMATION

- If you should experience any negative outcomes from this research, please be aware that you may contact Cal Poly Campus Health & Wellbeing, at (805)-756-1211, for assistance.

- This research is being conducted by graduate student Ben Johannes, and faculty advisor, Michael D. Whitt, PhD, MBA in the Department of Biomedical Engineering at Cal Poly, San Luis Obispo. If you have questions regarding this study or would like to be informed of the results when the study is completed, please contact the researcher(s) at mdwhitt@calpoly.edu, or at (805)-756-6433.

- If you have concerns regarding the manner in which the study is conducted, you may contact Dr. Michael Black, Chair of the Cal Poly Institutional Review Board, at (805) 756-2894, mblack@calpoly.edu, or Ms. Debbie Hart, Compliance Officer, at (805) 756-1508, dahart@calpoly.edu.

AGREEMENT TO PARTICIPATE

If you agree to voluntarily participate in this research project as described, please indicate your agreement by choosing an option and signing below, please retain a copy of this form for your reference, and thank you for your participation in this research.

___ Yes, I agree to participate and have my participation be recorded.

___ Yes, I agree to participate and have my participation be recorded, but would like to review the recording transcript before it is used in the analysis.

___ Yes, I agree to participate but do not allow my interview to be recorded.
APPENDIX C.

A. PROPOSED RESEARCH RATIONALE

Every year there are many injuries that occur in competitive downhill ski racing during a run in a giant slalom course. It has been determined that around 30% of injuries that happen involve the Anterior Cruciate ligament either with a partial or full tear of the ligament (Spörrri, Kröll, Gilgien, & Müller, 2017). This topic has not been thoroughly researched for biomechanical analysis due to how niche a problem this is, but it could be impactful in the safety of the athlete. A theory as to why these injuries occur could be due to fatigue in the legs that cause improper stance during crucial parts of a turn. Previous injury prevention studies have shown that a ratio of the quadriceps and hamstrings allow the skier to reduce shear stress on the knee joint (Spörrri, Kröll, Gilgien, & Müller, 2017). Taking shear stress off of the ACL will help reduce the chances of injury due to cyclic damage. The main mechanism of anterior cruciate ligament injury in World Cup alpine skiing appeared to be a slip-catch situation where the outer ski catches the inside edge, forcing the knee into internal rotation and valgus (Bere et al. 2011). In skiing rehabilitation or conditioning programs, a product is used called the Skier’s Edge. This device allows the user to mimic movements that would be completed while skiing. With this lateral movement, it is important to understand if this type of movement is helpful in conditioning for skiers or athletes who undergo lateral stresses in the sport in question.

The goal of this study is to analyze the Skiers Edge to see if skiers at different levels of skill will improve in control of muscle activity in key muscles in the leg. A comparison will be completed between the usage of the Skier’s Edge, an elliptical, and a traditional ski conditioning workout. This study will then assess if the Skier’s Edge improves lateral movement training in the lower limbs as an indicator of reduced ACL damage risk.

B. SPECIFIC PROCEDURES TO BE FOLLOWED Subjects will read the informed consent form and will be prompted to ask and further questions before signing the informed consent.
Subjects will be instrumented with 13 surface (skin-mounted) electrodes located on the vastus medialis, vastus lateralis, biceps femoris, semitendinosus, gluteus maximus, and rectus abdominis. Subjects will be instrumented with reflective markers located unilaterally on the toe, ankle, knee, and greater trochanter joints. Subjects will be recorded with still images to capture valgus angles in the knee.

Subjects will stand on a piece of paper with heels together and the legs externally rotated to provide a foot tracing that indicates active range of external rotation. Subjects will stand on heel-toe force transducers placed under the subjects shoes to collect balance data (center of pressure) in a laboratory setting and will perform 3 standard squats. Subjects will then perform several lateral movements using the Skier’s Edge T7 ski conditioning machine with balance bar. (1) The subject executes 30 seconds of movement on the Skier’s Edge on the high setting to collect maximum voluntary contraction of muscles instrumented with surface electrodes. (2) The subject will then complete 1 minute of movement on the Skier’s Edge at a set tempo of movement with surface electrodes, and force transducers on the heel and toe to collect ground reaction force data.

After initial collection subjects will then complete an assigned conditioning workout every three days a week for a four-week duration. Subjects will then be randomly assigned to three groups. Group 1 will be subjects who only use the Skier’s Edge T7 for conditioning training. The training with use of the Skier’s edge will include the use of the Skier’s Edge T7 on the medium setting to allow the use for all skill levels for 15 minutes a session. Group 2 will be subjects who only use an elliptical for conditioning training for 30 minutes a session. Group 3 will be subjects who only use a traditional ski conditioning workout for conditioning training. The traditional ski conditioning workout is as follows: Squats with free weights, leg press machine, or your own body weight (3 sets of 5 reps), one-legged squats with 45 to 90 degrees knee flexion (3 sets of 5 reps), Standing lunges (both forward & diagonal,3 sets of 10 reps), Balance on one leg with your knee slightly bent and move the other leg out and in, and back and forth (3 sets of 5 reps), Standing or lying leg lifts (3 sets of 5 reps), Calf raises on a step (3 sets of 5 reps), Core exercises: Hanging Leg Raise (3 sets of 5 reps).

After four weeks of completing the assigned ski conditioning workout the subjects will then perform several lateral movements using the Skier’s Edge T7 ski conditioning machine with balance bar. (1) The subject executes 30 seconds of movement on the Skier’s Edge on the high setting to collect maximum voluntary contraction of muscles instrumented with surface electrodes. (2) The subject will then complete 1 minute of movement on the Skier’s Edge at a set tempo of movement with surface electrodes, and force transducers on the heel and toe to collect ground reaction force data. Kinematic data will be collected via 2D video capture and video analysis software and foot tracing. Kinetic data will be collected with heel-toe force transducers placed under the shoe of the participant for ground reaction force and moment
Electromyographic data will be collected with surface electrodes placed on the skin to measure muscle activity.

C. SUBJECTS TO BE INCLUDED

Subjects for the proposed investigation include novice to expert level skiers, novice meaning up to several months of skiing experience and expert meaning greater than 10 years of skiing experience. There will be a minimum of 30 subjects that will be ranging from novice to expert skiers. Subjects will be all genders ages 18-30 years old. No participants will be excluded based on minority. Subjects must be free of neurological and or musculoskeletal impairment that will impact balance (e.g. cerebellar disorder, debilitating arthritis). Subjects with previous ligamentous injury to the lower extremity or any current injury that prevents participation in the study will be excluded. Impairment will be determined through subject self-report.

D. RECRUITMENT OF SUBJECTS AND OBTAINING INFORMED CONSENT

Subjects will be recruited with flyers and by word-of-mouth. Flyers will be posted at training areas and common areas to inform interested persons about the research. The flyers will an e-mail address and phone number for contact. In addition, a researcher will visit the areas to provide information and answer questions. To avoid coercion, potential participants are free to leave the area during the visit and informed that they do not need to stay. The potential participants will be contacted by phone to determine if any neurological or musculoskeletal disorders are present and to fully describe experimental procedures. The risk of use of the Skier’s Edge will be fully explained in the initial phone contact before the potential participant indicates willingness to participate in the study. The potential participant will be prompted to ask any questions about subject participation. If the participant is willing to participate, a time for data collection will be set. On the day that the participant visits the lab for data collection, procedures and risk will be fully described. The experimental session and data collection will not proceed without explicit consent of the participant. The participant must sign a consent form prior to participation. The participant will be encouraged to ask any questions and will be informed that the experiment can be terminated at any time should they wish to stop. If the participant wishes to not participate and terminate the experiment, they will remain anonymous.

E. CONFIDENTIALITY

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 will be referred to using the number or letter code of the particular subject only. Subject names will only on (1) Project Master List, and (2) Signed Written Consent forms. This information will be kept in an official study binder. Only the PI, co-PI, and Faculty Advisor will have access to the Official Study Binder.
F. POTENTIAL RISKS TO SUBJECTS The experiment tasks proposed present the risk of falling or injury from the operation of the Skier’s Edge. This risk is no different from that experienced while training or actively participating in skiing, or during some everyday physical activities. To alleviate this risk, the subject will warm up by jogging for one minute and completing stretches to the lower limbs. Subjects will be asked to fill out the Physical Activity Readiness Questionnaire to determine if you are able to be enrolled in the study. There will be two persons always present during the study, one of whom is certified in CPR techniques and the other ready to call medical services if a subject requires it.

G. BENEFITS TO BE GAINED BY THE INDIVIDUAL AND/OR SOCIETY There are no direct benefits for the individual subject. The results of this study will increase our understanding of the biomechanics of the joints and muscle activation during the use of the Skier’s Edge as compared to traditional methods of conditioning.

H. INVESTIGATOR’S EVALUATION OF THE RISK-BENEFIT RATIO The overall risks are minimal in relation to the information that will be gained.

I. WRITTEN INFORMED CONSENT FORM Please see sample of consent form on the following page.

J. WAIVER OF INFORMED CONSENT OR SIGNED CONSENT N/A

K. SUPPORTING DOCUMENTS

Written Consent Form Skier’s Edge, Talent Model Release Form Skier’s Edge, Standard Location Release Form Flyers for Skiers, Physical Activity Readiness Questionnaire
**APPENDIX D.**

**MVC EMG DATA**

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## APPENDIX E.

### INTEGRAL EMG DATA

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VALGUS ANGLE AND FORCE DATA REGRESSION MODELS

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### APPENDIX H.

**EMG DATA**

**EMG INITIAL DATA**

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| Semitendinosus Left    | 0.752 |

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Semitendinosus (MVC) Right | Semitendinosus (MVC) Right |
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### APPENDIX I.

**RECRUITMENT Flier**

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**Skiers Wanted at all Skill Levels!**

**Biomedical Engineering Thesis Project**
**Biomechanical Analysis of Skier’s Edge Ski Conditioner**

![Image of ski equipment]