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# FORCE AND STABILITY ANALYSIS OF REHABILITATED ANTERIOR CRUCIATE LIGAMENT INDIVIDUALS

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# FORCE AND STABILITY ANALYSIS OF REHABILITATED ANTERIOR CRUCIATE LIGAMENT INDIVIDUALS

by

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ABSTRACT


FORCE AND STABILITY ANALYSIS OF REHABILITATED

ANTERIOR CRUCIATE LIGAMENT

INDIVIDUALS



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The anterior cruciate ligament (ACL) serves as a vital stabilizer for the human knee, yet it is one of the most injured ligaments in the body. While surgery and physical therapy can restore function to the injured knee, those who rehabilitate from an ACL tear may never regain their former performance capabilities. To better understand the influence of rehabilitation on ACL performance, this study evaluated strength and stability differences within the legs of 11 individuals who have rehabilitated from an ACL repair. Y-Balance Tests and a Biodex isokinetic dynamometer were used to measure dynamic knee stability and strength, respectively. No significant differences were found in the strength test measurements. However, differences in Y-Balance Test composite scores (-2.8±3.1%, $p = 0.014$) and maximal anterior reaches (-2.8±2.4cm, $p = 0.010$) were found to

be significantly different. Consequently, both balance measurements in the involved legs were significantly impaired when compared to the uninvolved legs.

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# CHAPTER 1

# INTRODUCTION

Among the four major ligaments that stabilize the human knee, the anterior cruciate ligament (ACL) is debatably the most impactful. Opposing hyperextension of the knee, the ACL not only limits excessive movements, but also has been noted to be the primary stabilizing ligament to the tibiofemoral joint.[16] Despite its significance, the ACL has been reported as one of the most injured ligaments in the body, resulting in almost 200,000 tears annually and often associated with participation in sports.[11] Even though ACL injuries are common, not all individuals undergo surgery. Those who do partake in surgery undergo ACL reconstruction, which involves grafting tissue from another tendon to serve as a replacement for the torn ligament.[13] Subsequent to surgery, rehabilitation would follow, varying in specificity from program to program. In many of the rehab programs, key components such as strength, stability, and flexibility are tested and improved to discharge patients back to activity and exercise.[8] For organized sports and physical activities, completion of specific "return to sport" protocols are recommended for physical therapists to safely discharge patients to perform in games.[7] Although athletes are often required to reach these minimal requirements before being discharged and returning back to play, not all ACL patients will receive the additional rehabilitation. Furthermore, even with these protocols, the prevalence of developing osteoarthritis following ACL reconstruction positively increases.[7, 13]

Of the various components tested with rehabilitation, stability is a key element to consider when examining a newly reconstructed ligament of the knee. Several previous studies have examined this variable through use of the normalized dynamic stability tests like the Star Excursion Balance Test and Y-Balance Test. For instance, a 2016 study using the Star Excursion Balance Test compared dynamic knee stability between ACL-rehabilitating individuals who had functional range of motion to a healthy control group; it was discovered that the rehabilitating individuals performed worse than the control group on the dynamic stability test in both limbs.[2] In a study conducted by Smith et al., occurrence of noncontact injury and active athletes' stability was examined while using the Y-Balance Test; from their results, Smith et al. found that certain movements on the Y-Balance Test, specifically motion in the anterior direction, related to increased prevalence of injury.[11] Other investigations, such as Bulter et al.'s 2013 study on collegiate football players, have suggested that Start Excursion Balance Test and Y-Balance Test composite scores can help determine the likelihood of future lower limb injuries.[1] Consequently, these findings suggest that ACL injury and reconstruction surgery do have a correlation to instability and potential future knee injuries. Using multiple questionnaires and functional tests, a study conducted by Risberg et al. documented the diminishment of disabilities/impairments such as pain, laxity in the knee, and range of motion in ACL reconstruction patients undergoing continual rehabilitation; the results showed that full recovery within the knee and quadriceps took as much as two years.[10] Thus, knee stability should not be overlooked by researchers or health professionals when evaluating functionality of individuals with ACL repairs.

Along with studies that focus on stability of the knee after ACL reconstruction, strength of the quadriceps and hamstrings also prove significant for functionality in the tibiofemoral joint. As with stability, multiple studies have been taken to examine the influence ACL reconstruction has on strength. For instance, Wilk and Andrews conducted isokinetic tests with the Biodex isokinetic dynamometer to determine tibial force and angular velocity for individuals with ACL-deficient knees; from their findings, Wilk and Andrews noted that increased angular velocities resulted in decreased force production.[14] Additionally, a study conducted by De Carlo et al. compared variables of strength and range of motion of individuals undergoing accelerated rehabilitation of ACL reconstruction, as opposed to those who underwent traditional rehabilitation. Upon their research, De Carlo et al. found that earlier strength and range of motion gains took place in the accelerated rehabilitation program.[4] Also, from their study, it should be noted that the Biodex isokinetic dynamometer was not used; rather, a similar machine known as the Cybex II isokinetic dynamometer was used to measure force with isokinetic.[4] In regards to ACL functionality and strength tests, a study was conducted by Wilk et al. on individuals who underwent ACL reconstruction within two years of testing.[15] From their results, Wilk et al. found a direct relationship between multiple one-legged functional test scores and isokinetic peak torque collected with the Biodex dynamometer.[15] Furthermore, the participants in that study showed a significant difference in peak torque values between legs.[15] In this way, these studies validate the importance of assessing strength.

The purpose of this research was to analyze the strength and dynamic stability in the legs of individuals who have undergone ACL surgery and rehabilitation. It was expected that the involved legs would show reduced performance on the strength and dynamic stability tests, relative to the uninvolved legs. While several studies have tested these variables on those who underwent ACL reconstruction, the findings of this research will provide further knowledge of how individuals function in regards to dynamic stability and strength measures following ACL reconstruction and rehabilitation.

# CHAPTER 2

# METHODS

## 2.1 Subjects

Eleven moderately active individuals (7 male, 4 female) who rehabilitated from an ACL repair participated in the study. The participants had a mean age of 23.1±3.51 years (range 18-31), mean height of 174.6±9.4 cm (range 160.0-190.5), and mean weight of 82.5±10.8 kg (range 67.3-97.7). Individuals with high blood pressure, hemophilia, heart disease, sickle cell trait, an acute infection, edema in the legs, a blood/bleeding disorder, a skin disorder on a lower extremity, or currently pregnant were excluded from the study. Also, individuals who are taking anti-inflammatories or muscle relaxers were excluded from the study. For those included in the study, participants had to be released back to activities of daily living by a health care professional (self-reported), had one surgical knee intervention for an ACL injury over six months prior to beginning participation in the study, had undergone rehabilitation for their ACL injury, and had no self-reported anterior knee pain. Participants with an ACL reconstruction surgery or ACL avulsion fracture repair were included in the study. No stipulation on ACL reconstruction graft type was made. Additionally, six of these participants had meniscus repairs to accompany their ACL surgery; two participants had medial collateral ligament sprains, but no surgical intervention was required. There were nine participants who underwent surgery on their left leg, and the remaining two had surgery on their right leg. The mean time in physical therapy was 6.4±2.11 months, and the mean amount of time since surgery was 6.01±4.79

years. Prior to participating in the study, participants completed a health history questionnaire and informed consent form approved by the University of Texas at Arlington's Institutional Review Board. All testing was completed at the Biomechanics Lab in the Maverick Activity Center at the University of Texas at Arlington.

## 2.2 Y-Balance Instrument

A Y-Balance device was made by hand with three long pieces of masking tape. The handmade Y-Balance design was directly based off Plisky et al.'s Y-Balance dimensions.[8] Thus, the three pieces of tape were placed in the anterior, posterolateral, and posteromedial directions to form a Y (see Appedix A). Using a protractor, the posterolateral and posteromedial pieces of tape were placed at 135° angles from the anterior piece of tape.[8] Consequently, a 90° angle formed between the two posterior pieces of tape.[8] A line was drawn directly at the center of the Y-Balance, where the three pieces of tape intersected; this line was used to represent the "Starting Line." A pen was used to mark the distance that the participant's leg reached for each trial. A *Komelon® Speed Mark™* tape measure was used after each trial to determine the participant's leg reach.

### *2.2.1 Procedures of the Y-Balance Test*

The procedures followed for the Y-Balance Test were based on Plisky et al.'s study.[8] Thus, participants were instructed to wear tennis shoes, shorts/athletic pants, and a t-shirt.[8] For each trial, participants stood on one leg at the center of the Y-Balance.[8] The grounded foot was situated so that the most distal portion of the participant's shoe lay directly behind the Starting Line.[8] Once at this starting position, participants were instructed to extend their ungrounded leg in one of the three designated directions (posteromedial, posterolateral, anterior) and lightly tap the masking tape with their foot.[8]

Immediately after the participant touched the tape, a pen mark was made on the tape where the most distal portion of the foot hit the ground. A tape measure was used to determine the distance reached in centimeters. The order in which participants completed the three directions remained the same: first anterior for both legs, second posteromedial for both legs, and third posterolateral for both legs.[8] Each direction began with the right foot first, and then the left foot.[8] Following Plisky et al.'s standardized warmup protocol, participants completed six practice trials on both legs for all three directions to become familiarized with the movements.[8]

A set of criteria were met during each leg reach in order to consider the trial successful.[8] Consequently, participants were required to stand on one leg throughout the trials.[8] Participants were not allowed to have their reach foot use the ground for support.[8] Participants had to return their reach foot to the starting position under control.[8] Participants were not allowed to raise the heel of their grounded foot throughout the trial. In the event a participant violated any of the criteria, additional trials were completed until the required number of valid reaches were measured.[8] Before moving from one direction to the next, participants completed any additional attempts necessary.[8]

Immediately after completing the warm-up trials, participants were instructed to complete three official trials that did not violate any of the aforementioned rules.[8] After acquiring these measurements, the furthest reach in each direction was used to evaluate the reach distances individually.[8]

Finally, leg length was measured in both the left and right legs. Participants stood straight up, with feet shoulder-width apart. Each leg was measured from the top of the greater trochanter to the floor. In order to stay consistent with the test, participants kept their shoes on during the measurement.

*2.2.2 Y-Balance Scoring*

After measurements were made, reach data was evaluated for both legs in all three directions. Thus, a paired sample t-test was used to determine any difference between the surgical and nonsurgical legs in the Y-Balance Test. In order to normalize the data, reach distance was divided by limb length and multiplied by 100.[8] A composite score was also determined by adding together the largest reach distance of each direction, dividing this value by both 3 and limb length, and then multiplying the value by 100.[8]

## 2.3 Biodex Dynamometer

Participants were seated on a Biodex™ Isokinetic dynamometer, a standardized piece of equipment used to establish concentric muscle force (see Appendix A).[6] As based on Biodex procedure, participants were strapped at the thigh, shin, and pelvis to the Biodex seat.[6] After the participants were properly secured, they sat as they bent their knees at 90° angles. Full extension of the knee was considered as 0°, while a 90° knee bend was the parameter for flexion of the knee. The Biodex™ Isokinetic dynamometer was programmed to 180°/s to perform isokinetic flexion and extension at the knee.[6] As in previous studies, 180°/s has been a common angular velocity for isokinetic measurements.[6] Starting on the right leg, participants were instructed to forcefully flex to a 90° degree bend and extend the knee fully during the isokinetic trials.[6] The participants were also instructed to hold on to the designated handles beside their chair as they flexed and extended at the knee.

Participants had two practice trials of 10 flexions and extensions to become familiarized to the movement at submaximal strength; thus, participants were instructed to practice at approximately 70% of their maximal effort. For the recorded trials, one set of three maximal flexions and extensions was recorded. Between practice trials the participants had 30 seconds of rest. Between the practice trials and the recorded trials, one minute of rest took place. After completing the isokinetic movements in the right leg, the participants alternated to the left leg. From the Biodex software, the following variables were measured: peak torque, average power, total work.

## 2.4 Statistical Analysis

In order to analyze the data, a paired sample t-test was used on SPSS 23.0. Prior to conducting the analysis, statistical significance was established ($\alpha \leq .05$) for all variables. For the Biodex strength test, the following variables were compared between the uninvolved and involved leg: extension peak torque, flexion peak torque, extension total work, flexion total work, extension average power, and flexion average power. For the Y-Balance Test to assess dynamic stability, the following variables were compared between the uninvolved and involved leg: maximum anterior reach and composite score.

CHAPTER 3

RESULTS

No significant differences were found between the uninvolved and involved limbs for the Biodex strength test: extension peak torque ($p = 0.356$), flexion peak torque ($p = 0.172$), extension total work ($p = 0.488$), flexion total work ($p = 0.195$), extension average power ($p = 0.633$), and flexion average power ($p = 0.355$) (Table 3.1).

| | Uninvolved | | Involved | | Percent Deficit | Paired Difference | |
|---|---|---|---|---|---|---|---|
| Variable | Mean±SD | 95% CI | Mean±SD | 95% CI | Mean±SD | Mean±SD | p |
| Ext Peak Torque (N·m) | 130.4±36.4 | 106.0-154.9 | 123.7±25.9 | 106.4-141.1 | 0.236±17.2 | 6.7±22.9 | 0.356 |
| Flx Peak Torque (N·m) | 76.8±18.4 | 64.4-89.2 | 72.6±17.4 | 60.9-84.3 | 4.436±12.8 | 4.1±9.3 | 0.172 |
| Ext Tot Work (J) | 366.7±94.4 | 303.3-430.1 | 352.5±67.1 | 307.5-397.6 | 0.845±18.5 | 14.2±65.4 | 0.488 |
| Flx Tot Work (J) | 254.6±79.1 | 201.5-307.7 | 234.2±66.9 | 189.2-279.1 | 5.909±19.2 | 20.4±48.8 | 0.195 |
| Ext Avg Pwr (W) | 216.5±60.8 | 175.7-257.3 | 211.7±50.0 | 178.1-245.3 | -0.264±16.7 | 4.8±32.3 | 0.633 |
| Flx Avg Pwr (W) | 137.4±47.2 | 105.7-169.2 | 130.3±45.0 | 100.1-160.5 | 3.845±20.3 | 7.1±24.4 | 0.355 |
| Max Ant Rch (cm) | 63.5±5.8 | 59.6-67.4 | 60.7±7.2 | 55.9-65.6 | 4.5±5.0 | -2.8±3.1 | 0.014 |
| Max Comp Rch (%) | 95.9±5.0 | 92.6-99.2 | 93.6±4.1 | 90.9-96.4 | 2.3±5.0 | -2.8±2.4 | 0.010 |

Table 3.1: Performance on Biodex Strength Test and Y-Balance Test

A significant difference comparing the uninvolved to the involved Y-Balance Test composite score ($p = 0.014$) was found, with the mean paired difference being -2.8±3.1% (Table 3.1). The uninvolved mean for composite scores was 95.9±5.0%, and the involved mean for composite scores was 93.6±4.1% (Figure 3.1).

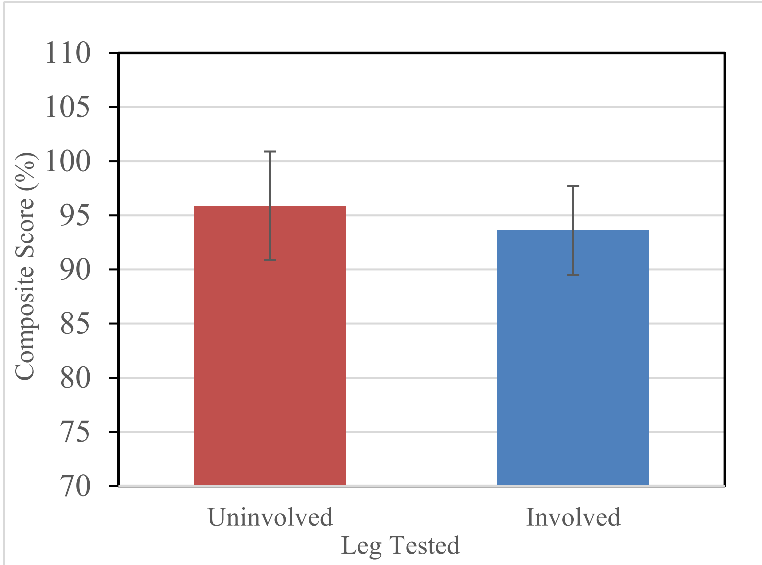


Figure 3.1: Mean Composite Score During Y-Balance Test

A significant difference comparing the uninvolved to the involved Y-Balance Test maximal anterior reach was found, with the mean paired difference being -2.8±2.4 cm (p = 0.010) (Table 3.1). The uninvolved mean for maximal anterior reach was 63.5±5.8 cm, and the involved mean for composite scores was 60.7±7.2 cm (Figure 3.2).

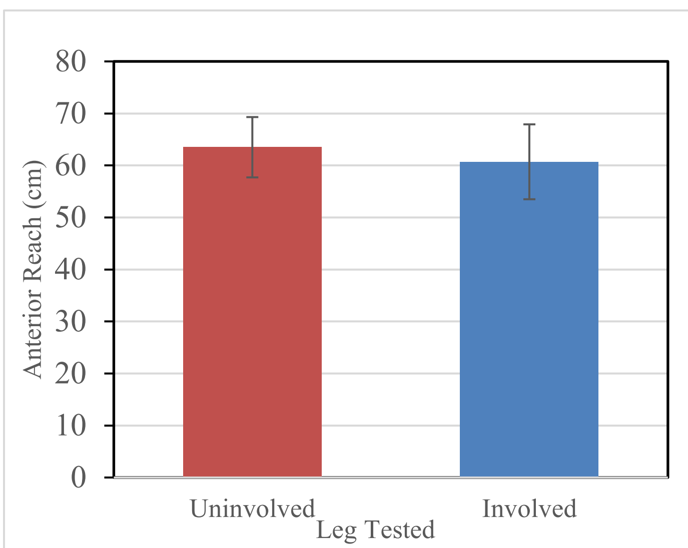


Figure 3.2: Mean Maximal Anterior Reach During Y-Balance Test

# CHAPTER 4

# DISCUSSION

The purpose of this study was to determine if dynamic stability and strength are inhibited for individuals who have rehabilitated from an ACL surgery.

For the tests in this study, it was determined that a significant difference was found in the stability test measurements (i.e., maximal anterior reach and composite score); thus, the uninvolved limb displayed greater dynamic stability than did the involved. This finding not only was hypothesized, but also corresponds to multiple studies involving the Y-Balance Test and Star Excursion Balance Test. For instance, Clagg et al. matched individuals with ACL reconstructed individuals to a healthy control group and used the Star Excursion Balance Test to evaluate dynamic stability differences.[2] Similar to findings of this study, Clagg et al. found a decrease in anterior reach for the ACL reconstructed group.[2] Clagg et al. also determined that certain individuals within the ACL reconstructed group, specifically those with a bone-patellar-bone graft, performed lower on the Star Excursion Balance Test.[2] Other studies, such as Plisky et al.'s 2006 study and Butler et al.'s 2013 study, show similar results with the Star Excursion Balance Test in the athletic populations.[1,9] Not only did both studies correlate decreased anterior knee reach to increased prevalence of lower limb injury, but both also showed increased prevalence with decreased composite scores on the stability tests.[1,9] In fact, Plisky et al.'s study found that female high school basketball players who scored below a 94% on their Star Balance Excursion Test composite score were 6.5 times more likely to sustain a lower limb injury in the future.[9] Furthermore, those females who had a deficit of 4 cm or more in their anterior reach were 2.5 times more likely to experience a lower limb injury in the future.[9] While Plisky et al.'s study notes to use the Star Excursion Balance Test, only the anterior, posterolateral, and posteromedial directions were used, which equates Plisky et al.'s methods to that of the Y-Balance Test.[9] Consequently, the aforementioned studies support the concept that individuals with surgical intervention to their ACL and rehabilitation are at increased risk of re-injury, due to increased instability. Moreover, these findings suggest that not enough stability training has been established during rehabilitation for these individuals.

In contrast to stability findings in this study, other studies have had mixed results when comparing injury to dynamic stability tests. For instance, in 2015 Smith et al. tested dynamic stability of collegiate athletes on the Y-Balance Test.[12] Smith et al. did not find any correlation between increased injury and the composite score of the Y-Balance Test; however, a direct relationship was established comparing maximal anterior reach deficit between limbs and prevalence of injury.[12] In a similar way, Delahunt et al.'s 2013 study somewhat contradicts the findings of this study, for Delahunt et al. did not find any significant difference in anterior reach on the Star Excursion Balance Test between healthy and ACL reconstructed female althletes.[5] However, based on other variables that evaluated knee joint kinematics, Delahunt et al. still concluded that ACL reconstruction with rehabilitation hindered stability.[5]

This study also evaluated the strength of individuals who have received rehabilitation from ACL surgery. From the Biodex™ Isokinetic Dynamometer strength test, no significant difference was found between the uninvolved and involved limbs for any of the strength variables (i.e., peak torque, total work, and maximal power). This outcome contradicted this study's hypothesis and the findings of various studies that also evaluated isokinetic strength in ACL reconstructed legs. For instance, Wilk et al. evaluated peak torque during isokinetic strength tests; from their results they discovered a direct relationship between subjective knee assessment scores and extension peak torque values at 180°/s.[15] Thus, Wilk et al. found an improved ability to generate force when subjects reported more stability and fewer symptoms.[15] Furthermore, Wilk et al.'s study displays a significant decrease in peak torque production in the involved leg at 180°/s.[15] In Cvjetkovic's et al's 2015 study, ACL reconstructed individuals who underwent hamstring training were compared to a healthy control group in isokinetic testing.[3] Cvjetkovic et al. found the ACL reconstructed individuals had generated a significantly reduced peak torque in the quadriceps at 180°/s.[3] Interestingly, though, there was no significant difference between groups for 60°/s peak torque in the quadriceps with extension.[14] Thus, Cvjetkovic et al.'s findings for 180°/s peak torque directly contradict this study's results. Simultaneously, Cvjetkovic et al.'s study shows a glimmer of similarity to this study's findings, since no significant difference was found in peak torque with extension at 60°/s. Thus, it may be possible that a true decrease in knee strength existed for the studied ACL reconstructed individuals, but the Biodex may not always detect a deficit within the involved limb.

The contrasting results found in this study could very possibly be due to the several limitations encountered within this study. First, the population size used was relatively small in comparison to many of aforementioned studies, which evaluated 50 or more individuals. Consequently, just a few statistical outliers could have potentially skewed the data, causing no statistical significance to be found in any of the strength tests. Second, the medical history screening may also have served as a limiting factor for this study. Both individuals with ACL reconstruction surgery and ACL repair were included in the study. Also, participants were not excluded from having a specific ACL graft type. Some individuals had additional complications (i.e., meniscus torn, MCL sprain) in the involved leg, which may have influenced individuals' performance in the tests. Furthermore, all medical history and rehabilitation was self-reported, and no restrictions were made on when the surgery and rehabilitation occurred. Thus, these factors decrease standardization of the participants. Additionally, any activity completed outside of the lab prior to testing could decrease performance in one leg over the other. As mentioned in Wilk and Andrews' 1993 study, changing the placement of the Biodex pad on an individual can change the peak torque output during isokinetic testing significantly.[14] Thus, lack of pad placement precision by the tester could have also served as a limitation to this study.

Due to the various limitations and the contradicting results on the isokinetic strength tests, this study should be replicated with several recommendations. A future study mirroring this one should consider the following: increase the sample size, screen for only ACL reconstructed individuals who have the same graft type and underwent surgery within the same time period, screen for a specific gender, evaluate the physical therapy settings which individuals received rehabilitation, and analyze other variables associated with ACL tears, such as flexibility or tibial displacement differences between limbs.

# CHAPTER 5

## CONCLUSION

Individuals who have rehabilitated from an anterior cruciate ligament injury displayed a significant difference in their involved leg for maximal anterior reach and composite score of the Y-Balance Test. These same participants failed to display any significant difference in their involved leg for peak torque, total work, and maximal power during concentric extension and flexion at 180°/s on the Biodex™ Isokinetic Dynamometer. The Y-Balance Test results reflect previous studies, which suggest that greater instability exists in the knee following an ACL injury. Accordingly, a greater emphasis on increasing dynamic knee stability should be made during physical therapy to prevent future damage of ligaments and reduce the likelihood of developing osteoarthritis. The strength tests on the Biodex™ Isokinetic Dynamometer, however, do not correspond with many previous studies that evaluated isokinetic values for ACL reconstructed knees in relation to the unaffected limb. Consequently, it is recommended that this study be replicated with an increased and more standardized sample population.

# APPENDIX A

# ILLUSTRATIONS

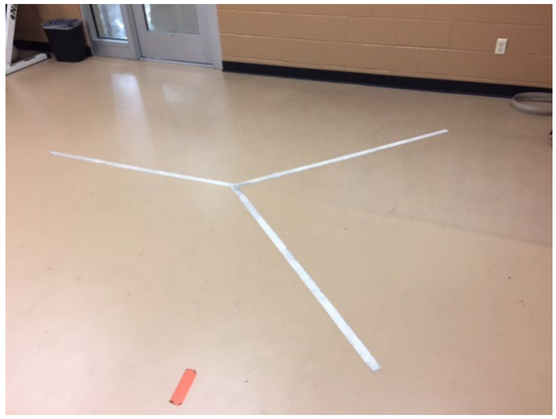

Figure A.1: Y-Balance Instrument


Figure A.2: Biodex$^{TM}$ Isokinetic Dynamometer

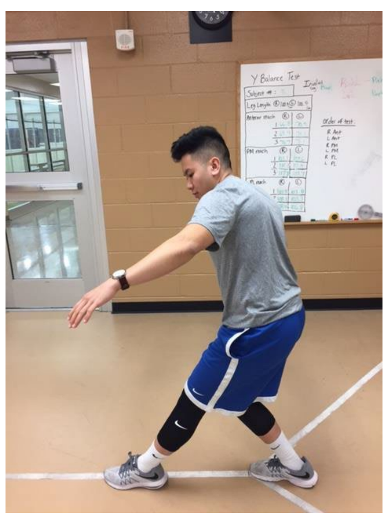

Figure A.3: Anterior Movement

Figure A.4: Posteromedial Movement

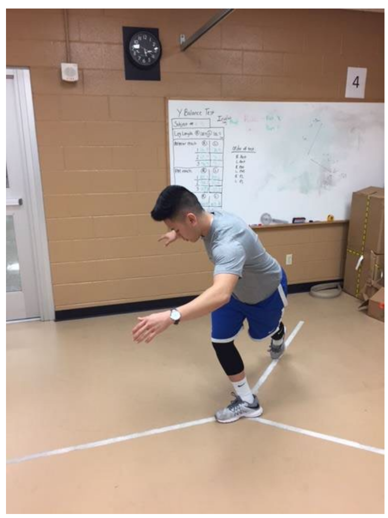

Figure A.5: Posterolateral Movement

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## BIOGRAPHICAL INFORMATION

Jeffrey Cervenka was born in Dallas, Texas, on August 19, 1996 and has lived Red Oak, Texas, all his life. In the fall of 2014, Jeffrey began attending the University of Texas at Arlington (UTA). Majoring in Kinesiology with aspirations to become a physical therapist, Jeffrey engrossed himself in learning. As a student, Jeffrey has been involved in multiple organization across campus, including National Society of Leadership and Success, the Society of Kinesiology Scholars, the UTA Honors College, and University Tutorial and Supplemental Instruction.

During Jeffrey's time at UTA, he was involved in multiple research labs in the Kinesiology Department, including Dr. Matthew Brother's vascular physiology lab and Dr. Mark Ricard's biomechanics lab. For Dr. Yilla's research methods course, Jeffrey presented research on running cadence and music tempo at the undergraduate research day for the Kinesiology Department. For his Honors Senior Project, Jeffrey wished to incorporate his interest of physical therapy into his research. Consequently, Dr. Ricard has served as Jeffrey's mentor as he analyzed the strength and stability of individuals who have rehabilitated from an ACL injury. This thesis contains the research study that was conducted and presented in the spring of 2017.

Jeffrey intends to graduate *Summa Cum Laude* in May 2017 from UT Arlington, and he has been accepted to the Doctor of Physical Therapy program at the University of Texas Southwestern Medical Center starting in Summer 2017. Jeffrey appreciates all who have touched his life as he continues his lifelong journey of learning.