Knee Brace With Inertial Based Controllers Approach to Knee Injury and Prevention of ACL Tear by Implementing Newton's Physics

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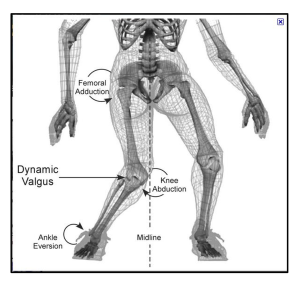
Background Information

The anterior cruciate ligament, or ACL, is a ligament that runs diagonally across the knee, connecting the femur to the tibia —the two main bones in the leg. The ACL restrains anterior translation of the tibia, prevents hyperextension of the knee, acts as a secondary stabilizer for stress to reinforce the medial collateral ligament, and controls rotation of the tibia on the femur in femoral extensions of 0°- 30°. An estimated 250,000-300,000 ACL ruptures are reported every year in America. A ligament cannot regrow due to the lack of blood flow, and therefore requires surgery and many months of physical therapy. Due to this large recovery period, it is crucial to focus on preventative measures.



Knee abduction movement, which is when the knee shifts away from the midline of the body, is a common risk factor for ACL injuries. Knee abduction movement over 25.3 Newton-meters increases the risk of an ACL injury. Knee abduction movements are commonly found in exercises like squatting, lunging, jumping, landing, leg dips, gait, and running. Currently, athletes must visit a physical therapist or a clinic to assess their knee abduction.

Many athletes are unaware of the ACL injury, and its vast repercussions. ACL prevention techniques are generally implemented into an athlete's regimen after they have gone through a reconstruction surgery. Exercises that focus on balance, agility in changing direction, jumping and landing safely, squats, and lunges are commonly used in physical therapy following an ACL reconstruction surgery to prevent future ACL injuries.

Introduction

This project aims to allow athletes to understand their risk of ACL injury by means of a knee brace. This brace has accelerometers, a type of inertial sensor, that track acceleration in three axes. By relating the acceleration to torque, which is the basis of knee abduction movement, the amount of knee abduction can be shown. Because the amount of knee abduction that is considered safe and unsafe is known, athletes will be able to understand when their motions translated to unsafe knee abduction, which shows them their risk of tearing their ACL. By understanding the risk of tearing their ACL, athletes can implement preventative techniques into their training.

Goals

The overarching goal for this project is to help athletes understand their risk for tearing their ACL so they can use preventative exercises. This goal was achieved by designing a knee brace that tracks acceleration in three axes and writing a program that can translate acceleration to torque to show athletes when their motions had safe and unsafe knee abduction.

Design Constraints

1. The knee brace cannot disrupt the normal motions of the athlete.
2. Sensors cannot be large in size.
3. Sensors and boards must be wearable devices.
4. Sensor or board must have memory capacity.

Design

The accelerometers must be placed in spots where they can measure acceleration that translates to knee abduction. In initial designs, there were six sensors that were placed alongside either side of the leg. However, the final design contains only two sensors that are placed on either side of the knee at the midpoint. This final design allows for two readings of knee abduction, and does not provide excess data that cannot be translated to knee abduction as the initial design did. It also prevents the knee brace from unnecessarily interfering with the athlete's motions.

Data

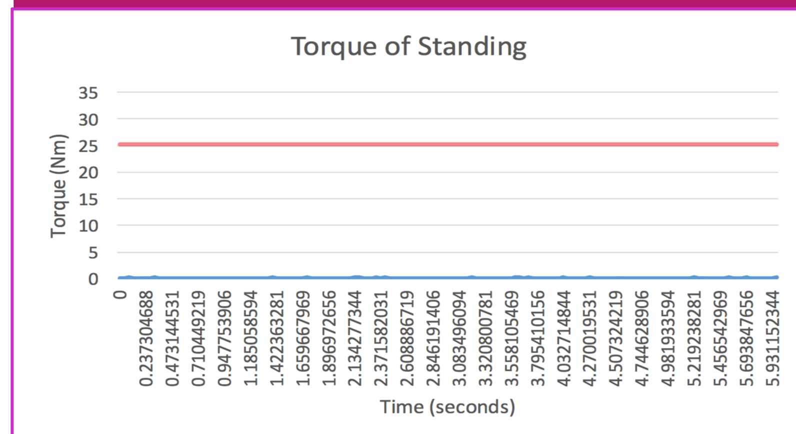


Figure 1: This graph represents the torque while standing still

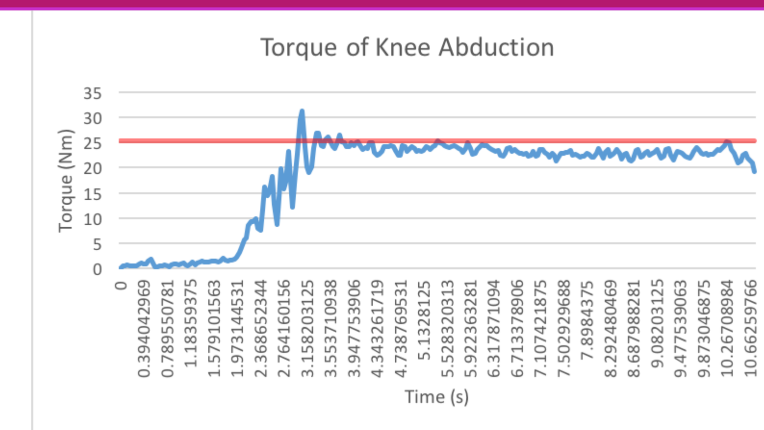


Figure 2: This graph represents the torque while mimicking the motion of knee abduction

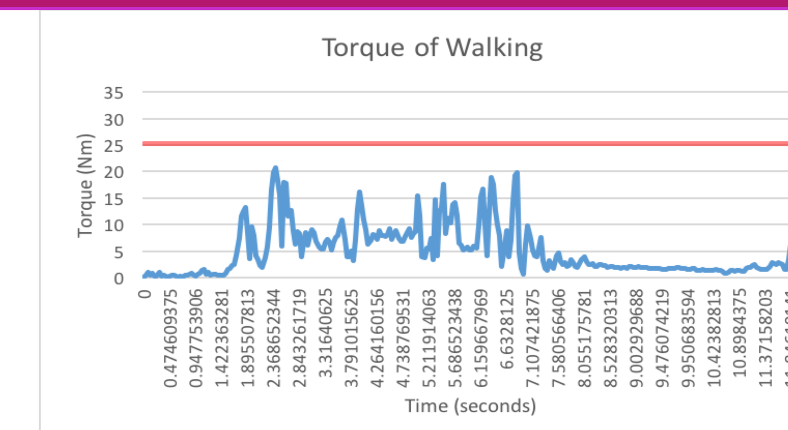


Figure 3: This graph represents the torque while walking

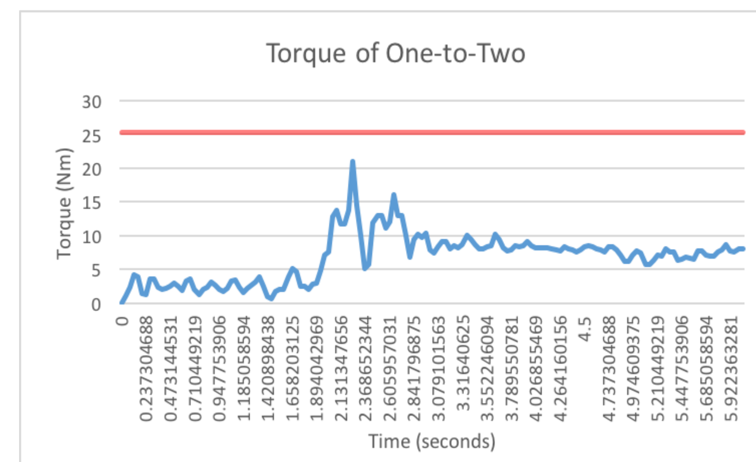


Figure 4: This graph represents the torque while jumping off one foot and landing on two feet

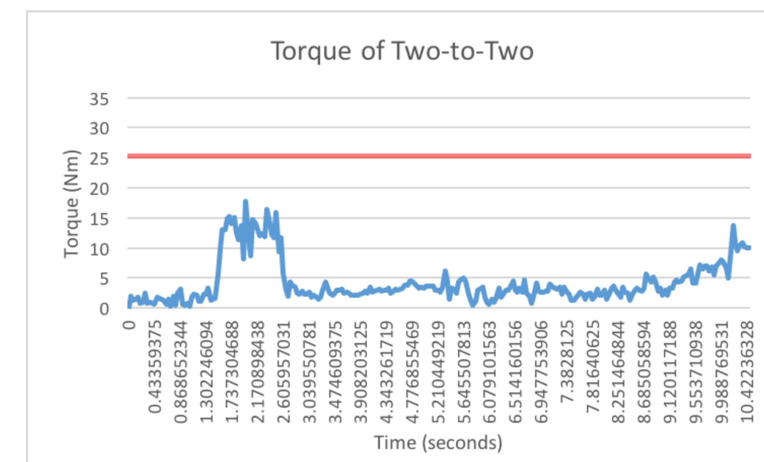


Figure 5: This graph represents the torque while jumping off two feet and landing on two feet

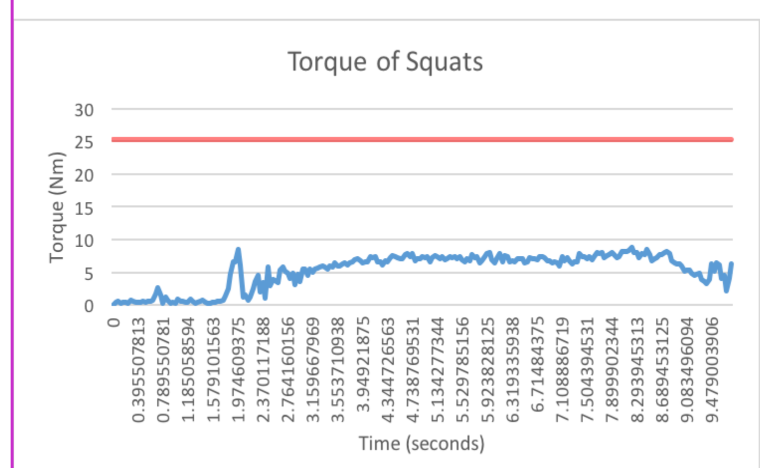


Figure 6: This graph represents the torque while squatting with two legs

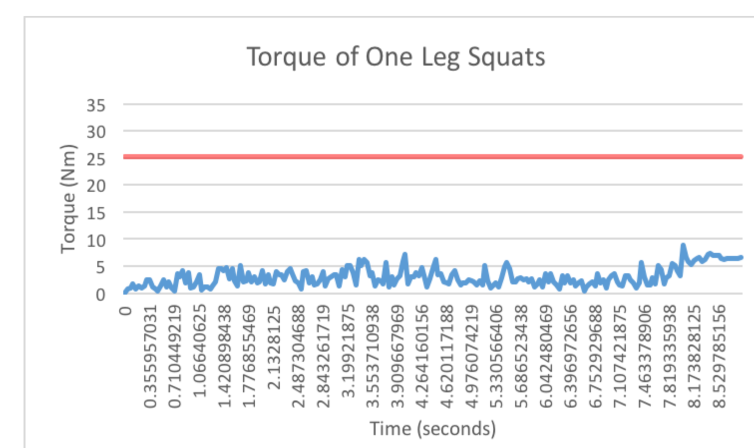


Figure 7: This graph represents the torque while squatting with one legs

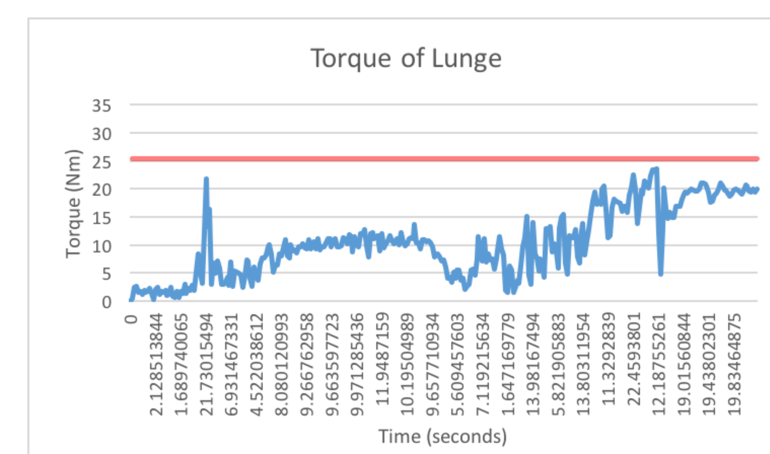


Figure 8: This graph represents the torque while squatting with one leg

Physics Principles Applied to Program

Using **Newton's Second Law for Rotation**, the acceleration of the knee was correlated to torque in order to detect knee abduction.

Newton's Second Law for Rotation:
T = torque
I = mass moment of inertia
α = angular acceleration

$$\boxed{T = I\,\alpha}$$

In order to measure torque, the calculations of the mass moment of inertia and angular acceleration were needed. The mass moment of inertia was calculated by representing the limb from the ankle to the knee as a solid cylinder.

M = mass of body
R = radius of leg
L = length of ankle to knee

$$\boxed{\text{InertiaCOM} = 1/4MR^2 + 1/12\ ML^2}$$

To calculate the angular acceleration, the magnitude of the three axes was taken at the point when the largest change in x-acceleration occurred to give the tangential acceleration.

Using the circular motion formula, α = R t (α = angular acceleration, R = radius of leg, t=tangential acceleration), the angular acceleration could be identified.

The angular acceleration and mass moment of inertia can then be applied into Newton's Second Law for Rotation to find the torque.

Pseudocode Algorithm

Data File Format:

The files available for processing are in the comma separated value (CSV) format, with the following items per column

X-axis (Angular Acceleration in <g>)
Y-axis (Angular Acceleration in <g>)
Z-axis (Angular Acceleration in <g>)

Goal: Calculate the Maximum Torque on the knee

Algorithm:

(Java Class: ReadingValues)

- Import BufferedReader, BufferedWriter, FileReader, FileWriter, IOException, PrintWriter and StringTokenizer to read in and write out to files
- Read the data file and parse the values of time, x, y, z angular acceleration into separate arrays
- Initialize x-maxDiff to zero
- Initialize max-Index to zero
- For each x value set read,
  - Calculate the difference compared to x original values
  - If the differential is larger than x-maxDiff
  - Set the x-maxDiff to the new difference
  - Set the max-Index to the new index
  - Return the final x-maxDiff and the maxIndex

Pseudocode Algorithm (cont.)

(Java Class: ReadingValues) cont.

- Extract the y and z values at the maxIndex and calculate the y-Diff and z-Diff by finding absolute value of difference between index value and original value
- Calculate magnitude of tangential acceleration by take the square root of the sums of the squares of x-maxDiff, y-Diff, z-Diff
- Return the tangential acceleration to TorqueCalculator

(Java Class: TorqueCalculator)

- Import BufferedReader, BufferedWriter, FileReader, FileWriter, IOException, PrintWriter and StringTokenizer to read in and write out to files
- Initialize the pi constant to use in calculations
- Read the data file and parse values to store into length, radius, and mass variables
- Calculate the inertia center of mass
- Calculate the mass moment of inertia by adding the inertia center of mass with the shift
- Call a method to ReadingFiles to retrieve the tangential acceleration from sensorial data
- Calculate angular acceleration with tangential acceleration
- Find torque using Newton's Second Law of Rotation
- If the calculated torque is greater than 25.3Nm
  - Print torque
  - Warn user of knee abduction and to take preventative measures
- Else
  - Print torque and inform user of no knee abduction

Results

To assess the validity of this program, the acceleration measured during specific exercises was translated to torque. This torque was then compared with the results measured in a standard physical therapy test. As a control, we measured the individual torque for the standing still data, from which we could confirm that the torque variation was minimal, staying under a measurement of 0.8 Nm. For a mimicked action of knee abduction, we found that the torque begins at zero and predictively grows larger over time, hitting a torque of over 25.3 Nm. This aligns with the expected results, proving that the knee brace and program can accurately determine knee abduction. Other movements such as squats and jumps were tested for torque, and there were no moments in which torque surpassed 25.3 Nm and knee abduction was observed. **Overall, the data corresponded with the observations that were made in a standard physical therapy test, proving that this program has the ability to accurately translate acceleration to knee abduction during controlled exercises, and the risk of ACL tears can be shown.**

Conclusions

There was one overarching goal outlined at the beginning of the project: To help athletes understand the risk for tearing their ACL so they can use preventative exercises. Throughout this project, a knee brace that uses accelerometers to track acceleration throughout exercise was developed. Then a program translating acceleration to torque was designed by integrating physics into algorithms. **This program has the ability to accurately determine the amount of torque from the acceleration in a controlled environment.** By incorporating concepts of physics, algorithms, and knee kinetics, the engineered knee-brace accurately provides athletes with the abduction measurements of their knee, and thus enables them to understand their potential risk for ACL tear and can thus implement preventative techniques in their training.

This knee brace and program also has the capacity to treat other issues based on knee abduction. One example of this is patellofemoral pain syndrome, in which likelihood of developing PFP is indicated by knee abduction of greater than 15 Nm during landing exercises.

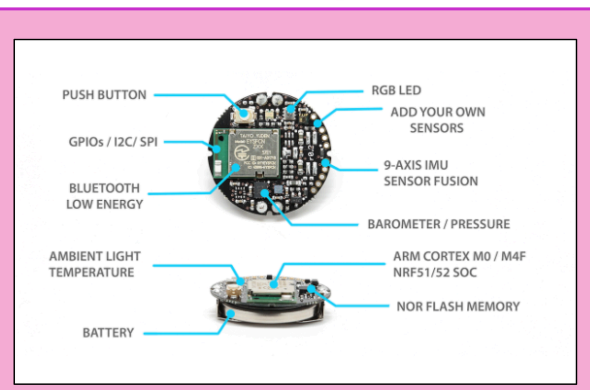
Further Research

1. Reduce potential error by using a geometrical figure that more accurately represents the shape of the limb from the knee to the ankle.
2. Using two centers of mass to more accurately represent the motion of torque
3. Implementation of this knee brace into gameplay.

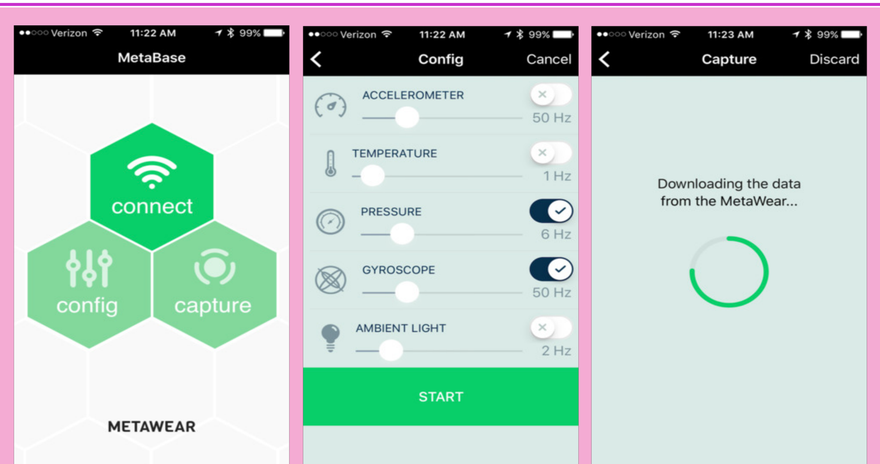
Rehabilitative Knee Brace

Prophylactic Knee Brace

Compression Knee Sleeve



MBientLab Sensors used to measure acceleration and gyroscope data



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