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Extended essay cover

Diploma Programme subject in which this extended essay is registered: Sports, exercise and health science.

(For an extended essay in the area of languages, state the language and whether it is group 1 or group 2.)

Title of the extended essay: Do hamstring and quadriceps muscle activation patterns differ between dominant and non-dominant leg during athletic maneuvers in 16-17 year old females.

Candidate's declaration

This declaration must be signed by the candidate; otherwise a grade may not be issued.

The extended essay I am submitting is my own work (apart from guidance allowed by the International Baccalaureate).

I have acknowledged each use of the words, graphics or ideas of another person, whether written, oral or visual.

I am aware that the word limit for all extended essays is 4000 words and that examiners are not required to read beyond this limit.

This is the final version of my extended essay.

Extended essay supervisor's report

Candidate name:

School name:

Examination session: May 2014

Supervisor:

Comments:

The scope of this essay is unique. I am extremely impressed with the robustness of her experimental investigation. 's essay is well planned and a good variety of source types are used for supporting information. She spent MANY extra hours fine-tuning data collection strategies as well as best techniques to feather out the details necessary to produce the graphs you see on page 16. This speaks to her overall determination, motivation, and 'stick-with-it-ness'. I think the relevancy of the topic and the depth of treatment shows very good intellectual initiative and insight. The research question is relevant and of an appropriate scope to be explored within the word limit. Her research methodology was sound and I am impressed with her discussion around experimental limitations and how she might improve a similar study in the future. Her approach was well planned and the essay developed at a good pace. An appropriate amount of background literature research from a variety of sources was done to support the essay.

I am confident the final product is 's and no malpractice took place.

Assessment form (for examiner use only)

Criteria	Examiner 1	maximum	Examiner 2	maximum	Examiner 3
	Achievement level				
A research question	2	2		2	
B introduction	2	2		2	
C investigation	3	4		4	
D knowledge and understanding	4	4		4	
E reasoned argument	3	4		4	
F analysis and evaluation	4	4		4	
G use of subject language	4	4		4	
H conclusion	2	2		2	
I formal presentation	4	4		4	
J abstract	2	2		2	
K holistic judgment	4	4		4	
Total out of 36	34				

Do hamstring and quadriceps muscle activation patterns differ between the dominant and non-dominant leg during athletic maneuvers in 16-17 year old females: relevance to identifying risk factors for non-contact ACL injuries.

Candidate number:

Subject: Sports Exercise, and Health Science

Supervisor:

Word count: 3584

Abstract

Research Question Do hamstring and quadriceps muscle activation patterns differ between dominant and non-dominant leg during athletic maneuvers in 16-17 year old females.

Objective This study intends to look at the difference between hamstring and quadriceps muscle activation patterns between the dominant and non-dominant leg in relevance to identifying risk factors for anterior cruciate ligament (ACL), among female soccer players (age: 16.8±0.4 years; height: 5.5±.0.27 ft; weight: 127.9 ± 8.6 lbs). The purpose was to test the two hypothesis: 1) that the non-dominant leg will have greater quadriceps activity compared to the dominant leg and 2) that the non-dominant leg will have less hamstring activity compared to the dominant leg.

Methods A 4 gate Fusion Sport Smart Speed timing reaction system was set up on the Acadia turf and synchronized with the video analysis software (Dartfish) and the EMG data acquisition software. The timing reaction system enabled the cutting maneuvers to be unanticipated in nature and more game like in nature. The first two gates provided an approach speed and the remaining two gates were positioned to the right and left sides and guided the athlete to change directions and either cut off their dominant or non-dominant leg.

Results Hypothesis 1 was accepted and hypothesis 2 was rejected. There was a strong trend for greater quadriceps activity in the non-dominant leg in both the swing and stance phase, (P values of 0.07 and 0.02) however the hamstrings were not statistically different in swing and stance (P values of 0.53, 0.37).

Conclusion The results that show the strong trend for greater quadriceps activity in the non-dominant leg prove the point of the non-dominant leg being more at risk in females.

Abstract word count: 276

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Introduction

A torn anterior cruciate ligament, commonly known as the ACL, is a common injury that could negatively impact someone's sports career. In sports where there is a sudden change in direction, sudden stopping, deceleration, landing a jump, or direct tackles, your ACL can be torn[1]. A statistic from the American Academy of Orthopedic Surgeons states that 70% of ACL injuries in athletes can happen due to these non contact mechanisms, where there has been no direct contact to the knee,[4] which is why the unanticipated side cutting maneuver method is being used for testing dominant versus non-dominant leg. The swing and stance phase of the subject when they preform the maneuver will be examined. Swing phase is the phase where the foot is off the ground, while the stance phase is when the foot is in contact with the surface. The side cut maneuver is when the subject runs, then plants their right foot to go left, and vice versa. Light guiding gates are used to replicate a real game like situation, where there could be a possible ACL injury. Research has shown that unanticipated maneuvers generate higher muscle activation maneuvers, as well as generating greater loads at the knee.[7] The knee is placed at greater risk during cutting maneuvers due to medial and lateral muscle imbalances for the quadriceps and hamstrings.[7] The quick change in direction is recognized as a common injury mechanism, especially in females, related to non-contact ACL ruptures.[7]

This essay investigates whether the muscles such as the hamstring and quadriceps, activation patterns differ between the dominant and non-dominant leg in females, and to what extent. Dominant versus non-dominant legs are being used simply to create a comparison. This information will help demonstrate whether females activate their quadriceps or hamstring muscles more in their dominant or non-dominant leg. This will help in concluding what leg is more at risk. Through experimenting and researching, the goal is to determine whether there is a significant difference between the hamstrings and quadriceps muscle activity between dominant and non-dominant leg. The results from this experiment will be valuable for me individually as well as for teammates and players in sports prone to ACL injuries, to help us understand the way our body works and how to avoid injury.

An ACL tear is an injury I have never experienced, however I have friends, both male and female who have torn theirs, leading to great disappointment, such as not being able to play on high level soccer teams. While I have seen friends take a downward spiral due to this injury, I have learned it does no have to be this way for everyone. One of the top female soccer players who plays for the US woman's national team, Alex Morgan, tore her ACL just five years before the Olympic games in London where she scored the game winning goal to send America to the gold medal game. Recovery is possible, and an ACL injury doesn't end a true athletes career.

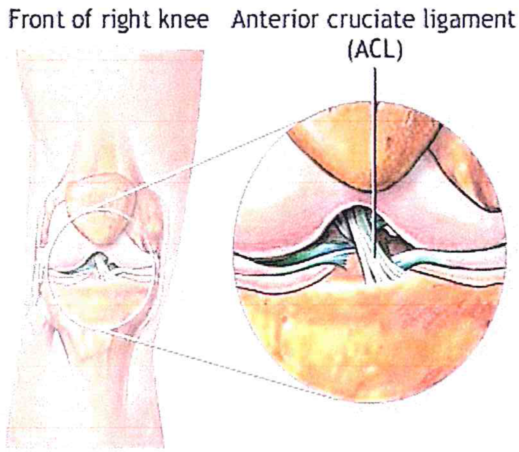
I feel as though ACL prevention research could be very valuable, as it already has been, especially for women, because it is something that has been damaging to people's sport career and confidence. Due to previous research by others, I have already been involved in ACL prevention activities. It has been included into workouts and training I have participated in, where the team focus' on decelerations, landing jumps, and side cutting. Continuing research will only help us all understand more, and hopefully lower the risk of tearing an ACL while it is an issue seen both locally and globally.

Anatomy of the ACL, Hamstrings and Quadriceps

The anterior cruciate ligament is found inside your knee joint (Figure 1) and forms an X with the posterior cruciate ligament being in the back of the X. These cruciate ligaments control the back and forth motion of your knee.[1] The job of the ACL is to provide stability to the knee. The ACL does this by limiting anterior translation and internal rotation of the tibia with respect to the femur. (Cheryl et al. 2005) During dynamic tasks, the ACL can be excessively loaded and strained. Lack of neuromuscular control however, exposes the ACL to excessive loads, placing the ACL at a higher risk of being damaged. (Cheryl et al. 2005) If an ACL injury were to occur, you must get surgery to repair or reconstruct the ligament because the ACL won't heal on its own.

Throughout this essay and lab, the muscle activation patterns of the hamstring and quadriceps will be explored. These two muscle groups have been chosen because, with proper coordination and co-contraction, they are critical in protecting the ACL[7]. They are also the main dynamic stabilizers of the knee along with the gastrocnemii's.[7] The quadriceps may significantly increase the loads on the ACL (Markolf et al., 2004; More et al., 1993) making it more at risk for injury, however it does contract eccentrically to prevent excessive knee flexion at peak activation levels which occurs around the midstance[3] (Colby et al., 2000; Neptune et al., 1999; Ciccotti et al., 1994a). As for the hamstring, it is an agonist to the ACL by aiding in resisting anterior tibial translation and rotations[11]. (Renstrom et al., 1986; Arms et al., 1984)

Figure 1: ACL placement in the knee



Females and ACL injuries

Females are 2 to 10 times more likely due to tear their ACL[3]. One of the most common reasons that researchers have proposed is the fact that females have greater quadriceps and less hamstring activity compared to males. This can be seen as a risk factor in regards to ACL injuries because when the quadriceps are contracted at flexion angles less then about 45 degrees, it can increase ACL strain by pulling the tibia anteriorly.[7] (Landry et al 2007) While the hamstrings have the potential ability to lower the stress on the ACL by being co-contracted.[7] Therefore if females have greater quadriceps activity compared to hamstring activity, there would be more strain on the ACL. There are also many other sex specific risk factors that are known in literature as intrinsic which are considered to be uncontrollable. (Harner et al 2000) These factors include measures such as lower limb alignment, intercondylar notch width, quadriceps femoris angle (Q angle), joint laxity, navicular drop, or subtalar joint pronation, and size of the ACL.[5]

When comparing dominant versus non-dominant, females are more likely to injure their preferred supporting leg (non-dominant leg) while males are more likely to injure their preferred kicking leg (dominant leg), however neuromuscular studies have not reported consistent differences between dominant and non-dominant lower extremity.[2] Other research papers have looked into the difference in strength in dominant and non-dominant legs, and have found no significant differences.[9] There are more risk factors for making women more likely to injure their ACL that include the factor of females demonstrating less hip and knee flexion, less hip and knee internal rotation and less hip abduction.[5] Also females demonstrated larger knee abduction and foot pronation angles, and increased knee abduction and internal rotation variability.[5]All these factors were found when the subjects preformed a cutting maneuver.(Cheryl et al. 2005) While these are important factors in regards to ACL injuries, throughout this essay, the focus will be on the neuromuscular risk factors in regards to the hamstrings and quadriceps during cutting maneuvers.

The gender I am focusing on is females, because of the higher risk factor. Also, I am a female therefore the research will apply to me as well as my teammates. The females tested in my experiment will be aged 16-17 because according to the Norwegian National Knee Ligament Registry the most female ACL reconstructions happened between the ages of 15-19. Also according to Kaiser Permanente Southern California database, the highest ACL injury reconstruction number was found in females ages 14-17. All the females taking part, play soccer, which is a quadriceps and abductor dominated sport.[2]

Lab

Purpose

To test the muscle activation patterns of the quadriceps and hamstrings in the dominant and non-dominant leg to see what leg is more at risk for ACL injuries during side cut maneuvers. Tests were performed on female soccer players of varying levels of soccer aged 16-17.

Research Question

Do hamstring and quadriceps muscle activation patterns differ between the dominant and non-dominant leg during athletic maneuvers in females: relevance to identifying risk factors for non-contact ACL injuries.

Hypothesis

Brophy et al. showed that 68% of female ACL injuries occur on the non-dominant leg and injury risk factors that have been identified in the literature include increased quadriceps activity and reduced hamstring activity. Therefore based on the literature the following hypothesis were tested: 1) the non-dominant leg will have greater quadriceps activity compared to the dominant leg and 2) the non-dominant leg will have less hamstring activity compared to the dominant leg.

Methodology

Five female soccer players (experience ranging from recreational to Canada Games Provincial Nova Scotia Team) participated in this study (age: 16.8±0.4 years; height: 5.5 ± 0.27 ft; weight: 127.9 ± 8.6 lbs). All participants along with their guardian signed a consent form signed by their parents prior to arrival of testing. Upon arrival at the lab, the study was explained to the participants and the participants received a questionnaire on playing and injury history. Electromyography (EMG) wireless sensors were positioned on 7 muscles surrounding the knee (Table 1) (Figure 2) on both the dominant and non-dominant limb and the position of these sensors was based on established standards in the scientific literature.

Figure 2: Front and back view of the taping of the EMG sensors.

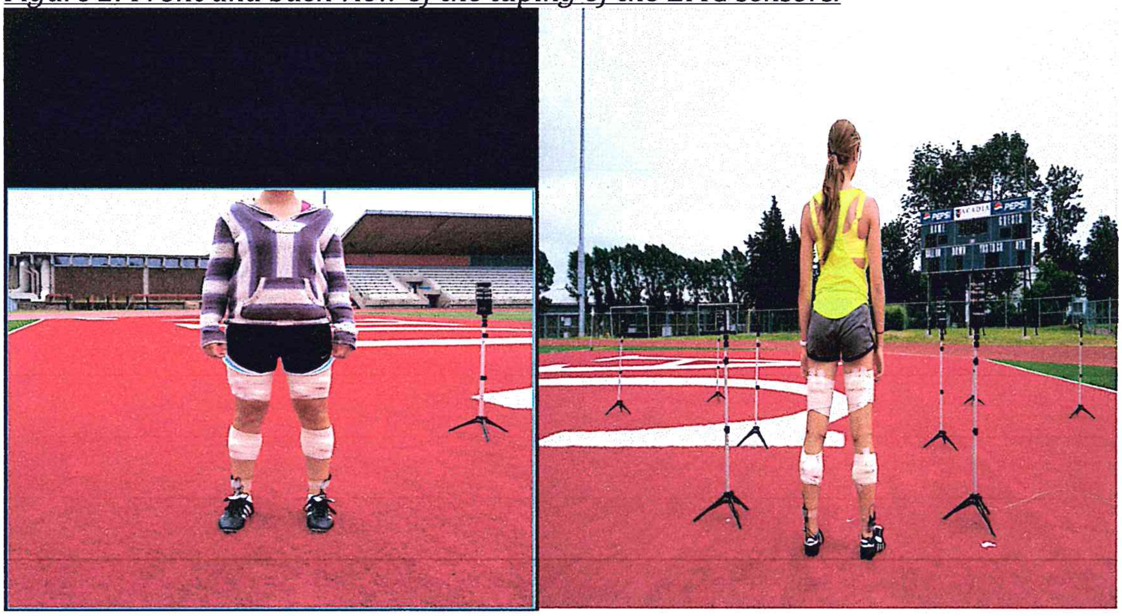


Table 1: Electrode placements for the 7 muscle sites surrounding the knee

Muscle Site	Location
Lateral Hamstring	50% of the distance from the fibula head to the ischial tuberosity (leg at 45°)
Medial Hamstring	50% of the distance from the medial joint line to the ischial tuberosity (leg at 45°)
Lateral Gastrocnemius	30% of the distance from the knee's lateral joint line to the calcaneus
Medial Gastrocnemius	35% of the distance from the knee's medial joint line to the calcaneus
Vastus Lateralis	25% of the distance from the knee's lateral joint line to the anterior superior iliac spine (ASIS) (leg at 45°)
Vastus Medialis	20% of the distance from the knee's medial joint line to the anterior superior iliac spine (ASIS) (leg at 45°)
Tibialis Anterior	33% of the distance from the fibula head to the medial malleolus (leg at 45°)

Note: Electrodes that are placed on the quadriceps, should be more proximal
Note: While electrodes are being placed on a variety of muscles, I will only be focusing on the hamstring and quadriceps.

Voluntary contractions were preformed to insure that quality signals were achieved for each muscle. A series of 24 maximum voluntary contractions (MVCs) that included knee flexion, knee extension, ankle plantar flexion, and ankle dorsi flexion (Table 2) were preformed on a Biodex dynamometer (Figure 3) and through manual resistance to magnitude normalize the muscle activity data obtained from the side cutting maneuvers.

Figure 3 Biodex set up with subject testing MVS's

Table 2: Maximum Voluntary Contraction exercises on the Biodex machine

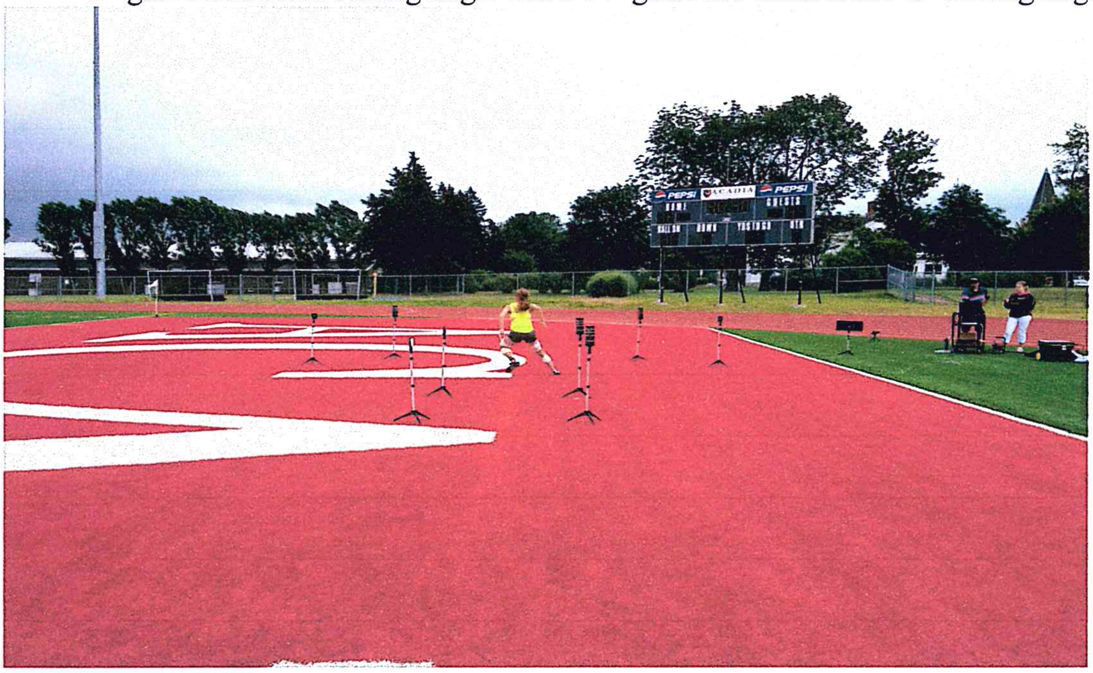
Trials	Leg	Muscle Group	Exercise
1	Right	Quadriceps	Extension (45°)
2			
3	Right	Hamstrings	Flexion (45°)
4			
5	Right	Gastrocnemii	Plantarflexion (90°)
6	(left on Biodex)		
7	Right	Tibialis Anterior	Dorsiflexion (90°)
8	(left on Biodex)		
9	Left	Gastrocnemii	Plantarflexion (90°)
10			
11	Left	Tibialis Anterior	Dorsiflexion (90°)
12			
13	Left	Quadriceps	Extension (45°)
14			
15	Left	Hamstrings	Flexion (45°)
16			
17	Right	Gastrocnemii	Standing Plantarflexion
18			
19	Left	Gastrocnemii	Standing Plantarflexion
20			
21	Right	Hamstrings	Flexion (prone, leg at 55°)
22			
23	Left	Hamstrings	Flexion (prone, leg at 55°)
24			

Note: Subjects will preform all exercises, however the focus will on be on only be on the hamstring and quadriceps for data collection.

Upon completion of the MVCs the participant was taken outside on the artificial field turf to preform the cutting maneuvers. A 4 gate Fusion Sport Smart Speed timing reaction system was set up on the turf and synchronized with the video analysis software (Dartfish) and the EMG data acquisition software. (See appendix B.) The timing reaction system enabled the cutting maneuvers to be unanticipated in nature and more game like in nature. The first two gates provided an approach speed and the remaining two gates were positioned to the right and left sides and guided the athlete to change directions and either cut off their dominant or non-dominant leg. After a proper warm up and practicing the maneuvers the participants preformed two maximum sprints through the timing gates. (Figure 4)

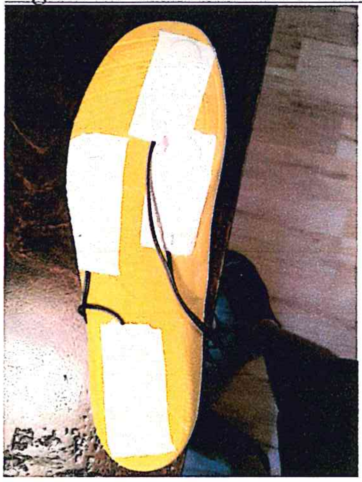
Figure 4: Set up for gate reaction system with me performing the test

-Set-Up Fusion Smartspeed System on the turf (1-1-2)
-Mark at 10m from first gate (100 Sprint Trial)
-Mark at 8.5m from first gate (200-300 Cutting Trials)
-1st and 2nd gates are 2m a part
-2nd gate 2.5m from cutting angle and 3rd/4th gates are 2.5m from 45° cutting angle



The times for the two sprint trials were averaged together and the approach speed for the cutting maneuvers was determined to be 75% of the average maximum sprint time ±10%. Participants were required to preform 5 successful trials on each side with a successful trail requiring planting off the proper foot, running through the proper gate, and having an appropriate approach speed. In order to time normalize the EMG data, and to determine the stance and swing phases of the cutting maneuvers, 4 foot switches were positioned in the insole of the left and right shoe. (Figure 5)

Figure 5: Foot Switch Placements



1. Base of 5th Metatarsal
. Base of Calcaneus
3. Base of 1st Metatarsal
4. Base of Hallux

Note: Provide slack for ankle mobility.

Synchronized video data, captured by Dartfish, was used to determine which stride during the 5 seconds of data collection was the cutting stride.

All processing of the raw EMG data was performed in Matlab using custom written software. The raw EMG data was bias corrected, full-wave rectified and low pass filtered at 6 Hz using a zero lag 4th order Butterworth filter.[12] (See appendix B.) To correct for biases and noise in the EMG signals, a subject bias trial with the subject lying completely relaxed and an EMG system bias trial were captured and subtracted from all EMG trials. A 100 msec moving window algorithm was used to identify maximum EMG amplitudes for the 14 muscle sites during the normalization exercises and these values were then used to amplitude normalize the EMG data during the cutting maneuvers.[6]

For the cutting maneuvers, 2 different phases of the EMG waveform data were analyzed and these phases included i) the pre-cut swing phase and ii) the cutting stance phase. The entire swing phase waveforms were represented with 101 data points ranging from 0% (foot off) to 100% (ground contact or foot on) in 1% increments. Similarly, the entire stance phase waveforms were represented with 101 data points ranging from 0% (ground contact or foot on) to 100% (foot off) in 1% increments. Each participant's muscle activity waveforms (both swing and stance phase done separately) for the 5 trials and for each of the specific muscles were average together to obtain an ensemble average waveform for each of the participant's muscles. These ensemble average waveforms for the vastus medialis and vastus lateralis muscles were averaged together for all 5 participants to obtain representative average waveforms for the quadriceps for both the dominant (cutting to the left) and non-dominant (cutting to the right) side. This process was also repeated for the hamstrings for both the swing and stance phases separately. Quantitative analysis of the overall magnitudes of the muscle activity waveforms were preformed by summing the waveform magnitudes at each time point for the subjects swing and stance phase. The medial and lateral sites for the quadriceps were both included in an analysis for both swing and stance, the medial lateral hamstrings were included in another analysis for both swing and stance and the ratio between the quadriceps and hamstring magnitudes for both swing and stance were included in the final analysis. For each of these 6 analyses, a paired T-test was preformed to determine if there was a difference in magnitudes between the dominant and non-dominant leg. A p-value less than 0.05 indicated a statistically significant difference, and a p value less than 0.1 but greater than 0.05 indicated a strong trend for a difference between the two legs[9] (Landry al et. 2007)

Variables

Table 3: Independent, dependent and control variables

Independent Variable	Dependent Variable	Control Variables
Side (dominant or non dominant) planting with a certain foot then going the opposite way	Quadriceps: The area under the curve	Speed (75% of max)
	Hamstrings: The area under the curve	Cutting angle
		Distances (Approach distance, cutting distance)

Data Collection and Processing

Raw Data Tables

Table 5: Heights and weights of the 5 subjects tested

Subjects	Height (ft/in)	Weight (lbs)
ABB	5'1	117
ABC	5'5	140
ABD	5'5	121
ABI	5'9	135
ABJ	5'7	125
	Mean	Mean
	5.54	127.6`

Processed Data Tables

Table 6: Approach Speeds in m/s of the right side cutting trials

Approach Speeds (m/s)						
Subject	C200 (Right) Trials					
	1	2	3	4	5	Mean
ABB	3.683	4.158	3.968	4.008	3.752	3.914
ABC	4.608	4.843	4.866	5.222	4.988	4.905
ABD	4.706	4.843	4.773	4.587	4.819	4.746
ABI	4.405	4.454	4.651	4.301	4.329	4.428
ABJ	4.914	4.608	4.854	4.673	4.329	4.676
					Group Mean	**4.534**
					Group STD	**0.387**

Table 7: Approach Speeds in m/s of the left side cutting trials

Approach Speeds (m/s)						
Subject	C300 (Left) Trials					
	1	2	3	4	5	Mean
ABB	3.802	4	4.065	3.876	4.098	3.968
ABC	5.115	4.515	4.376	0.141	4.957	3.821
ABD	4.843	4.902	4.785	4.796	4.866	4.838
ABI	4.494	4.184	4.264	4.376	4.228	4.309
ABJ	5.089	4.89	4.484	4.662	5.051	4.835
					Group Mean	4.354
					Group STD	0.475

Sample Calculations

Cutting Speed
To determine the cutting speed, the subject preformed 2 sprints and the average was taken. Using the average, I took 75% of that for their cutting speed.

Trial 200
Individual Mean
(3.683+4.158+3.698+4.008+3.752)/5= 3.914
Group Mean
(3.914+4.905+4.746+4.428+4.676)/5=4.534

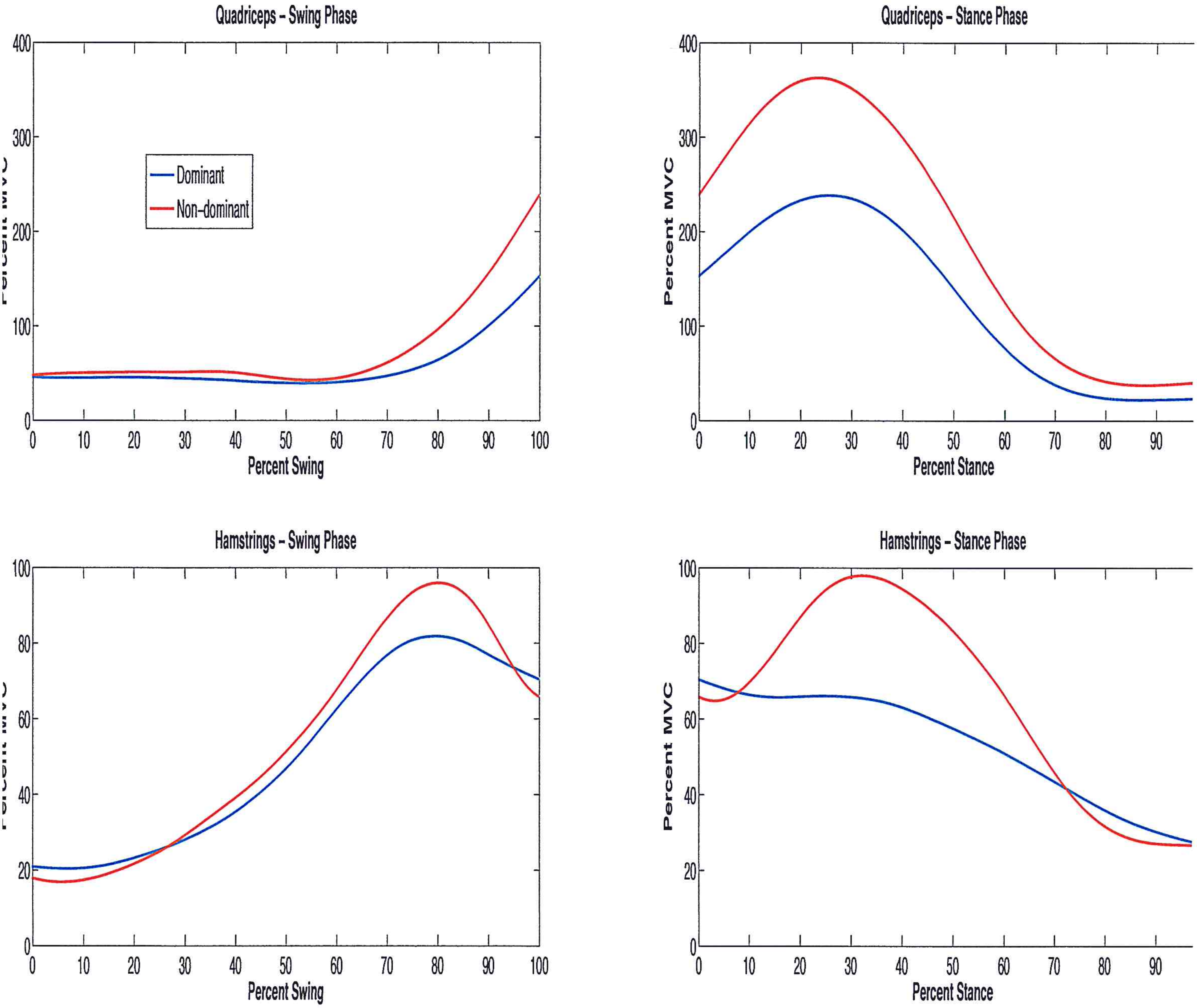
Trial 300
Individual Mean
(3.802+4+4.065+3.876+4.098)/5= 3.968
Group Mean
(3.968+3.821+4.838+4.309+4.835)/5= 4.534

Mean Heights
(5'1+5'5+5'5+5'9+5'7)/5 = 5.54

Mean Weights
(117+140+121+135+125)/5=127.6

Processed Graphs

Figure 7:
Percent MVC versus Percent Stance in stance and swing phase of both the quadriceps and hamstrings



Conclusion and Evaluation

Results

Research Question: Do hamstring and quadriceps muscle activation patterns differ between dominant and non-dominant leg during athletic maneuvers in 16-17 year old females.

After gathering the data and processing it into graphs, hypothesis 1 (that the non-dominant leg will have greater quadriceps activity compared to the dominant leg) was accepted, while hypothesis 2 (that the non-dominant leg will have less hamstring activity compared to the dominant leg) was rejected.

According to figure 3, the non-dominant leg demonstrated greater activity in the quadriceps and hamstrings, in both swing and stance phase. When looking at the quadriceps to hamstring ratio, it is shown that the ratio is not significant in swing phase (p value of .2) nor is it significant in stance phase (p value of .19). This could be due to the fact only 5 subjects were tested and there is always a lot of variability between subjects no matter the amount.

Table 8: Statistical Comparisons of overall Quadriceps and Hamstring activity and Quadriceps to Hamstring ratio between dominant and non-dominant legs during cutting maneuvers.

	Phase	Dominant Leg	Non-Dominant Leg	P Value
Quads	Swing	5760.59	7592.92	0.07
	Stance	12739.05	19739.67	0.02
Hams	Swing	5030.84	5402.92	0.53
	Stance	3334.30	6540.42	0.37

There was a strong trend for greater quadriceps activity in the non-dominant leg in both the swing and stance phase, however the hamstrings were not statistically different in swing and stance. These results prove the point of the non-dominant leg being more at risk.

Discussion

Due to the fact there were only activation measures, there is the question about the difference in strength. The non-dominant leg could have more activity because of the fact that it is weaker and it has to create activity at a higher level to generate the same force. In other words, the muscles would have to work harder when active, which would generate more activity. Saying that however, there have been studies that have found results that say there is no difference between the strength in dominant and non-dominant legs. The literature that stated this however tested on younger females, but the research is still relevant.[10]Another studies results showed that in male soccer players there was no obvious difference in muscle strength between dominant and non-dominant legs, however the sample size for the study was minimal.[8]

Something that really stuck out when looking at the results was the vastus medialis on the non-dominant leg. 4/5 of the subjects had activity levels 300% or higher of their MVC. This could be due to the fact the subject was having a hard time activating the vastus medialis on the MVC because the exercises are targeting the lateral part of the quadriceps. There is also the possibility that these subjects had weaker vastus medialis' and they had to activate them at higher levels during the cutting maneuvers. However, saying this, 1 out of the five subjects had high activity levels for both their dominant and non-dominant leg.

Focusing on the vastus medialis in the non-dominant leg and the dominant leg would be a good area for analysis because you could look into why the vastus medials couldn't get activated in the MVC's only in the non-dominant leg.

With the curves that were created it shows the quadriceps peaking in early stance phase. This makes sense because it is important for the quadriceps to contract to control knee flexion when landing. As for the hamstrings, a peak before they hit the ground is noticed. This is due to the fact they need to contract to slow down the leg, hip, and knee before landing as well as to protect the ACL. The second peak that is noticed in the hamstrings is possibly due to the fact one subject had high activity in mid-stance on the non-dominant leg.

Advantages of Experimental Design

Many studies have not examined the activation patterns in both legs, however, for this study there were enough activation measures to place on both legs to measure the activity levels on both legs from the MVCs to the side cut maneuvers.

Another positive aspect to the study was how realistic and game like the cutting maneuvers were. The participants were tested on a turf surface where many soccer games are held. The cuts that were preformed by the participants were preformed at a higher pace then most other research has. All participants were tested on the exact same surface, and all play soccer to make them more comparable.

Limitations of Experimental Design

-Didn't have strength measures to measure the strengths of the hamstrings and quadriceps. There were only activation measures, however as previously stated in this paper and other literature; there is no difference in strength between dominant and non-dominant legs.

-Although there was video, I did not have joint kinematic, which is motion capture that measures joint angles. Having this would have let me test for correlations between joint angles and neuromuscular measures.

-Weather varied from sun to run which could cause different results between subjects.

Suggestions for Improvement

-Get a better activity to measure the activation of the vastus medials on the MVC for the non-dominant leg

-Have all the subjects played the same level of soccer, or on the same team. This would give more specific results in relation to training load and competition.

-Only do testing on sunny clear days with similar wind pressures. Testing for all subjects could not be performed on a single day, due to the amount of time it takes for an individual to be tested.

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Appendix *A: Placement of sensors with corresponding number*

Table 9: EMG sensor numbers for the muscles

Leg	Muscle	Sensor #
Right	Foot Switch (RFS)	1
Right	Lateral Gastrocnemius (RLG)	3
Right	Medial Gastrocnemius (RMG)	4
Right	Lateral Hamstring (RLH)	5
Right	Medial Hamstring (RMH)	6
Left	Foot Switch (LFS)	2
Left	Lateral Gastrocnemius (LLG)	10
Left	Medial Gastrocnemius (LMG)	11
Left	Lateral Hamstring (LLH)	12
Left	Medial Hamstring (LMH)	13
Right	Vastus Lateralis (RVL)	7
Right	Vastus Medialis (RVM)	8
Right	Tibialis Anterior (RTA)	9
Left	Vastus Lateralis (LVL)	14
Left	Vastus Medialis (LVM)	15
Left	Tibialis Anterior (LTA)	16

Appendix B: ***Working Definitions***

BioDex
Rehabilitation technology used to address neuromuscular evaluation, therapeutic exercise, gait training and range of motion difficulties.

Butterworth Filter
A type of signal processing filter designed to have as flat a frequency response as possible in the pass band. The order of the filter (In the lab it is 4^{th} order) is the order of the polynomials.

DartFish
Develops performance enhancing sport video training applications and exclusive televised broadcast footage.

Electromyography (EMG)
A technique used for evaluating and recording the electrical activity produced by skeletal muscles.

Fusion Speed Timing gates
Wireless timing gate system for training and to understand and improve sport specific speed, agility, power and endurance.

Full-wave rectified
A rectifier that transmits both halves of a cycle of alternating current as a direct current.

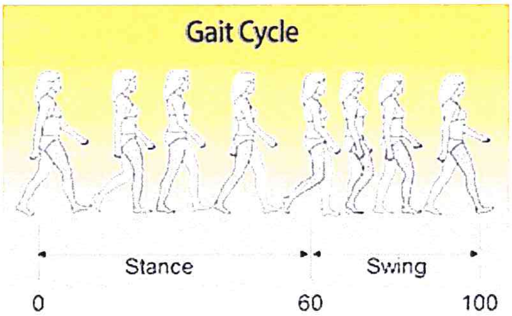
Matlab
A high-level language and interactive environment for numerical computation, visualization and programming used to analyze data and create models

Maximum sprints
Burst of speed while running at top pace.

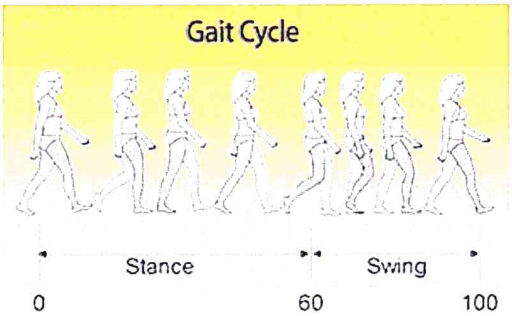
Maximum voluntary contractions (MVC)
The maximum force a muscle can generate, voluntarily, during a static contraction.

Muscle contractions
The act of shortening or tensing a muscle.

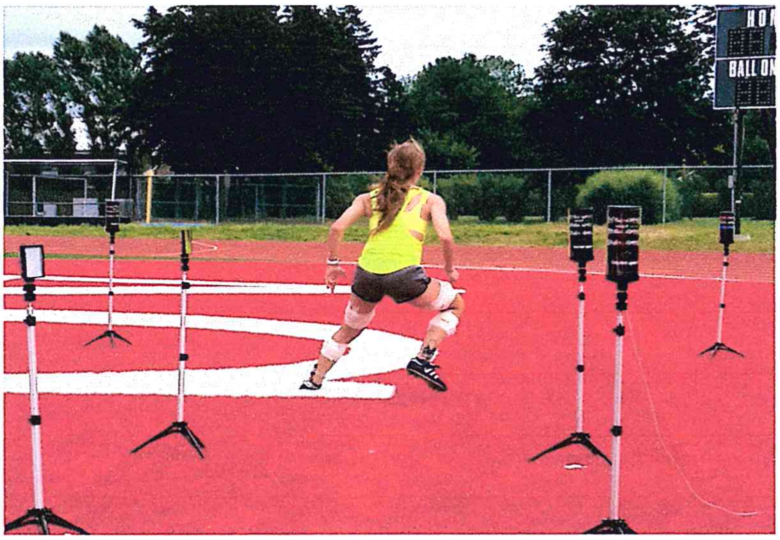
Stance Phase
Point where, when walking, one foot is in contact with the ground.



Swing Phase
Moving from full flexion to full extension.



Unanticipated Side Cut Maneuver
Planting one-way, and accelerating the other way in the direction of the lighted gate. The subject has no knowledge of what gate will light up, hence the unanticipated description. In this picture I planted left and accelerated right which was the direction of the lighted gate.



Appendix C: ***Consent form***

Consent Form

Do hamstring and quadriceps muscle activation patterns differ between the dominant and non-dominant leg during athletic maneuvers in females: relevance to identifying risk factors for non-contact ACL injuries.

The Researchers

You are being invited to participate in a research study by , a year 2 IB student at . She will be conducting the research under the supervision of , an Associate Professor in the School of . If you have any questions or concerns about the research both the principal investigators contact information is provided. If there are any question or concerns regarding the nature of the project, the contact information of the research ethics board is also provided.

Purpose of Research

The purpose of this study is to use surface electromyography (EMG) to understand how the muscles of the lower leg work when an athlete has to cut quickly to the side with little warning (running straight forward and changing direction quickly) and to compare the dominant versus non-dominant leg in females' aged 16-17. Understanding and identifying differences in the way the muscles crossing the knee joint work may help provide important information as to why females are at a greater risk than males for non-contact injuries to the anterior cruciate ligament (ACL) of the knee and if there is a difference in dominant versus non-dominant leg.

Research Involvement

As a current soccer player in the Soccer Association you have been selected as a potential participant in this study. You will be asked to perform a number of side-cutting maneuvers while running on the artificial turf field ( ). A light timing reaction system will be used to tell you to quickly cut to either the left or right side as quickly as possible, therefore making the movement closer to what you would do in a true game-like scenario. During the cutting maneuvers, the activity of several muscles on both legs will be recorded using a technique known as electromyography (EMG).

Small sensors that are a part of a Delsys Trigno 16-channel wireless EMG device will be placed onto the skin using double-sided tape over selected muscles of your legs. These sensors are able to measure the activity produced by a muscle when it contracts and this allows the researchers to precisely determine when your muscles turn on and off during the cutting movements. Hair will be removed from the skin by shaving at the appropriate locations where the sensors will be placed and the skin will then be cleaned with an alcohol swab prior to taping the sensors in place. Some redness or minor irritation may occur after removal of the sensors. There will also be two small devices that that will be placed in each of your shoes to determine when the foot is in contact with the ground and when it is not.

All testing will take place on and within the , which is located within . Prior to data collection, several practice trials of the side-cutting maneuver will take place, to familiarize you with the procedure. You will be asked to run through a timing gate system and carry out a side-cut movement cued by a coloured lighting system. The side to which you will be cutting will be randomly determined by a coloured light that will become visible once you have moved through the timing gates. You will be asked to complete five trials in each direction, which will be in a randomized order. An acceptable trial will be one that involves a successful side-cut maneuver in the correct direction and at an appropriate speed determined by the timing gate system. The quality of the EMG signal will also be assessed after each trial to ensure the EMG system is working properly and recording appropriate signals from all the muscles. One to two minutes of rest as well as water will be provided between trials or at any point in time that you feel necessary.

The study will end in the Laboratory where you will perform a series of maximum voluntary contractions on a Biodex dynamometer. This device measures the force that your muscles generate during a series of exercises and the EMG system will also measure the muscle activity levels of all the muscles during these specific exercises.

Full completion of the study should take no longer than 2.5 hours and this includes the setting up and placement of the sensors on you, the participant, as well as the execution of the cutting movements on and strength testing exercises in the Biomechanics Laboratory. You are asked to bring your own footwear (soccer cleats) for testing and you should come with your own t-shirt, pair of soccer shorts and short socks.

It is also important that you remember participation in this study is completely voluntary and withdrawing from the study at any point in time will in no way have a negative impact on your standing with your soccer team. You are also able to ask questions or address concerns at any time throughout the study.

Potential Harms

There are minimal risks associated with performing this study, as the side-cutting maneuver is a movement you are familiar with as a soccer player. Risk of injury is also very minimal, as you will be completing the study in a controlled setting. You will also be asked to complete a warm up and practice trials to decrease the risk of injury and familiarize yourself with the maneuver and equipment. A slight discomfort may be experienced or redness may become apparent when the tape and sensor is removed due to the shaving and removal of electrodes. By consenting to participate in this study, you do not waive your right to legal recourse in the event of any research-related harm.

Potential Benefits

There are no direct benefits to you as a participant; however, your contribution in this research will provide researchers, coaches, and athletes with a better understanding of ACL injury risks and injury preventive training programs could be enhanced based on results from this study.

Confidentiality

The data collected will be stored on a password-protected computer that will be locked in a cabinet within the Laboratory when not in use. The principal investigators and , will be the only people with access to the data. If the data is published or presented there will be no identification of yourself or any other participants.

Publications

Will be used as and Extended Essay and will be read by several people to mark.

Compensation

There will be no form of compensation provided upon completion of this study.

Participation

Your participation in this study is completely voluntary and you may withdraw from the study at any point in time without penalty. You may withdraw your data from the study within 30 days from testing, at which that point the data will be used in the principal investigators' Extended Essay theses. You are free to ask questions or address any concerns at any point in time before, during, and after the study.

Consent

By signing the informed consent I confirm that I have read and understood the nature of my participation. I verify that I have not had any lower extremity (hip, knee or ankle) injuries in the past six months or previous surgeries to the lower back or lower extremities. I also acknowledge that I am able to withdraw or ask questions at any time during the study without penalty. I am also aware that if I wish to withdraw my data from the study, I must do so within 30 days of data collection.

Participant:

Name: ___________________ **Date:** ________
(please print)

Signature: _______________

By signing the informed consent I consent to my child's participation in this study and have fully read and understood the nature of their participation. I also confirm that my child has not had any lower extremity (hip, knee or ankle) injuries in the last six months or previous surgeries to the lower back or lower extremities. I am aware that my child and I are free to ask questions and withdraw at any time during the study without penalty. I am also aware that if my child or I wish to withdraw the data from the study, we must do so within 30 days of data collection.

Guardian (if above participant is under 18 years of age):

Name: ___________________ **Relationship:** ______________ **Date:** ________
(please print)

Signature: _______________________

Witness:

Name: ___________________ **Date:** ________
(please print)

Signature: _______________________

Appendix *D: Signed consent forms (Alphabetical order according to last name)*

Consent

By signing the informed consent I confirm that I have read and understood the nature of my participation. I verify that I have not had any lower extremity (hip, knee or ankle) injuries in the past six months or previous surgeries to the lower back or lower extremities. I also acknowledge that I am able to withdraw or ask questions at any time during the study without penalty. I am also aware that if I wish to withdraw my data from the study, I must do so within 30 days of data collection.

Participant:

By signing the informed consent I consent to my child's participation in this study and have fully read and understood the nature of their participation. I also confirm that my child has not had any lower extremity (hip, knee or ankle) injuries in the last six months or previous surgeries to the lower back or lower extremities. I am aware that my child and I are free to ask questions and withdraw at any time during the study without penalty. I am also aware that if my child or I wish to withdraw the data from the study, we must do so within 30 days of data collection.

Guardian (if above participant is under 18 years of age):

Consent

By signing the informed consent I confirm that I have read and understood the nature of my participation. I verify that I have not had any lower extremity (hip, knee or ankle) injuries in the past six months or previous surgeries to the lower back or lower extremities. I also acknowledge that I am able to withdraw or ask questions at any time during the study without penalty. I am also aware that if I wish to withdraw my data from the study, I must do so within 30 days of data collection.

Participant:

By signing the informed consent I consent to my child's participation in this study and have fully read and understood the nature of their participation. I also confirm that my child has not had any lower extremity (hip, knee or ankle) injuries in the last six months or previous surgeries to the lower back or lower extremities. I am aware that my child and I are free to ask questions and withdraw at any time during the study without penalty. I am also aware that if my child or I wish to withdraw the data from the study, we must do so within 30 days of data collection.

Guardian (if above participant is under 18 years of age):

Consent

By signing the informed consent I confirm that I have read and understood the nature of my participation. I verify that I have not had any lower extremity (hip, knee or ankle) injuries in the past six months or previous surgeries to the lower back or lower extremities. I also acknowledge that I am able to withdraw or ask questions at any time during the study without penalty. I am also aware that if I wish to withdraw my data from the study, I must do so within 30 days of data collection.

Participant:

By signing the informed consent I consent to my child's participation in this study and have fully read and understood the nature of their participation. I also confirm that my child has not had any lower extremity (hip, knee or ankle) injuries in the last six months or previous surgeries to the lower back or lower extremities. I am aware that my child and I are free to ask questions and withdraw at any time during the study without penalty. I am also aware that if my child or I wish to withdraw the data from the study, we must do so within 30 days of data collection.

Guardian (if above participant is under 18 years of age):

Consent

By signing the informed consent I confirm that I have read and understood the nature of my participation. I verify that I have not had any lower extremity (hip, knee or ankle) injuries in the past six months or previous surgeries to the lower back or lower extremities. I also acknowledge that I am able to withdraw or ask questions at any time during the study without penalty. I am also aware that if I wish to withdraw my data from the study, I must do so within 30 days of data collection.

Participant:

By signing the informed consent I consent to my child's participation in this study and have fully read and understood the nature of their participation. I also confirm that my child has not had any lower extremity (hip, knee or ankle) injuries in the last six months or previous surgeries to the lower back or lower extremities. I am aware that my child and I are free to ask questions and withdraw at any time during the study without penalty. I am also aware that if my child or I wish to withdraw the data from the study, we must do so within 30 days of data collection.

Guardian (if above participant is under 18 years of age):

Consent

By signing the informed consent I confirm that I have read and understood the nature of my participation. I verify that I have not had any lower extremity (hip, knee or ankle) injuries in the past six months or previous surgeries to the lower back or lower extremities. I also acknowledge that I am able to withdraw or ask questions at any time during the study without penalty. I am also aware that if I wish to withdraw my data from the study, I must do so within 30 days of data collection.

Participant:

By signing the informed consent I consent to my child's participation in this study and have fully read and understood the nature of their participation. I also confirm that my child has not had any lower extremity (hip, knee or ankle) injuries in the last six months or previous surgeries to the lower back or lower extremities. I am aware that my child and I are free to ask questions and withdraw at any time during the study without penalty. I am also aware that if my child or I wish to withdraw the data from the study, we must do so within 30 days of data collection.

Guardian (if above participant is under 18 years of age):

Appendix E: *Reference Letter*

School of Recreation Management and Kinesiology

November 22, 2013

RE: 's role in research project

Dear Sir/Madame,

I would like to start by saying that I very much enjoyed having work with me and my research team this past year and she made significant contributions on many different levels over the past several months. approached me earlier this year about doing her IB research project under my supervision in my area of research, which involves using biomechanics to analyze athletes performing athletic maneuvers for the purpose of trying to understand and minimize the occurrence of devastating knee injuries (e.g. non-contact anterior cruciate ligament injury).

helped my research team develop and implement a testing protocol this summer where muscle activity sensors were placed on the quadriceps, hamstrings and calf muscles of both legs. With the sensors on both legs, athletes were asked to perform several muscle contractions on a strength-testing machine and then execute a series of unanticipated running and side-cutting maneuvers on an artificial FieldTurf soccer field. helped my three undergraduate honours students perfect this protocol by practicing it on a few occasions. Once they were comfortable with the protocol, recruited a number of her teammates to come visit the university for testing. Each testing took between 1.5 to 2.5 hours to complete and upon completion of all the data collections, spent several hours under my supervision processing and analyzing the muscle activity waveforms. Not only did recruit the participants in her own study, but she also helped with some other data collection sessions for my honours students. She helped with the setting up and tearing down of the testing equipment and she performed her own statistical analysis after I showed her an example of how to do and interpret one analysis.

I showed how to do a literature search on Pubmed and then she took it upon her self to gather articles and write up her final paper with very little input or help from me. She took great pride in her research project and she was an absolute pleasure to work with. is going to a university outside Nova Scotia next year but if she had chosen to come to , I would have approached her immediately about doing research in my lab because of how impressed I was with her work ethic and attention to detail. There is no question that is a very bright individual with a very very bright future ahead of her.

I hope this letter provides all the information you were looking for related to 's research project and paper. If you require any further information or have any questions about the project or about , please do not hesitate to contact me by phone ( ) or email ( ).

Sincerely,